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**Wearable Devices for Healthy Lifestyle Promotion and
Chronic Diseases Monitoring and Management**

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RIASSUNTO

Le malattie croniche non trasmissibili rappresentano una delle principali sfide di salute pubblica e sono strettamente legate a comportamenti modificabili quali attività fisica, sedentarietà e sonno. In questo contesto, l'accelerometria e conseguentemente l'actigrafia, integrate nei sistemi di *digital health*, consentono il monitoraggio continuo e oggettivo dei comportamenti nelle 24 ore (attività fisica, sedentarietà, sonno) e la loro integrazione con indicatori clinici e fisiologici. Per queste ragioni, gli obiettivi generali della presente tesi di dottorato sono stati: (i) analizzare la fattibilità e l'utilità di dispositivi indossabili basati su accelerometria in popolazioni e contesti differenti; (ii) integrare i segnali accelerometrici con misure cliniche, metaboliche e fisiologiche; e (iii) esplorare il potenziale di tali strumenti nella promozione di stili di vita salutari e nella gestione di condizioni croniche. Per rispondere a tali obiettivi sono stati condotti cinque studi, con disegni sperimentali distinti e complessità crescente. Nel primo studio è stata caratterizzata, tramite accelerometria da polso, l'attività sportiva del *plogging*, che combina corsa e camminata con raccolta di rifiuti in ambiente naturale. Sedici studenti universitari (età 22.50 ± 1.93 anni) hanno svolto una sessione di un'ora di *plogging* in spiaggia, indossando un accelerometro. I dati sono stati analizzati applicando diversi algoritmi per classificare i livelli di attività (sedentarietà, attività fisica leggera, moderata e vigorosa), per stimare i METs (Equivalenti Metabolici del Compito) e dispendio energetico. Sono state considerate tre condizioni: senza sovraccarico, con sovraccarico totale e con sovraccarico progressivo, modellando l'aumento del peso dei rifiuti raccolti nel corso dell'ora. I risultati hanno mostrato che una sessione di *plogging* si colloca nel range di intensità di METs compreso tra leggera e moderata, con la maggior parte del tempo trascorsa in attività fisica leggera e moderata e un incremento del dispendio energetico quando si considera il carico dei rifiuti. Questo studio fornisce una prima caratterizzazione fisiologico-indiretta del *plogging* e ne evidenzia il potenziale per programmi di promozione dell'attività fisica in contesti naturali.

Il secondo studio ha integrato l'accelerometria in un percorso riabilitativo rivolto a donne con incontinenza urinaria (IU). Venti donne tra i 40 e 70 anni, con IU lieve valutata tramite pad test a

48 ore (<30 g/48 h), sono state invitate a partecipare ad un protocollo di esercizio multimodale di cinque settimane. Il programma prevedeva 14 sessioni supervisionate e combinava esercizi per il pavimento pelvico, controllo della pressione intra-addominale, lavoro su postura e respirazione. Prima (pre) e dopo (post) l'intervento sono stati misurati: perdita urinaria tramite pad test, livelli di attività fisica quotidiana mediante accelerometria da polso (>15 h/giorno di wear time in entrambe le fasi), e percezione dei disturbi del pavimento pelvico tramite il questionario PFDI-20. I risultati hanno mostrato una riduzione significativa di perdita urinaria ($z = 3.92$, $p < 0.001$) e del punteggio totale del PFDI-20 ($p = 0.007$). I livelli di attività fisica (leggera, moderata e passi al minuto) non sono cambiati in modo significativo. Il calo del punteggio relativo ai sintomi urinari percepiti valutato tramite PFDI-20 ha superato i valori di Minimal Clinically Important Difference (MCID) riportati in letteratura per interventi conservativi e chirurgici, indicando un miglioramento clinicamente rilevante. Al baseline, l'attività fisica moderata era associata alla percezione dei disturbi del pavimento pelvico, mentre tale associazione è risultata attenuata e non più significativa dopo l'intervento. Le variazioni nella perdita urinaria e nell'attività fisica moderata hanno entrambe contribuito a spiegare i miglioramenti nella percezione dei sintomi, indicando che molteplici fattori possono sottendere gli effetti clinici osservati. Questi risultati supportano l'inclusione dell'accelerometria indossabile per monitorare i comportamenti di attività fisica nei programmi riabilitativi e suggeriscono che il miglioramento dei sintomi del pavimento pelvico non richiede necessariamente un incremento del volume di attività fisica abituale. Il terzo studio ha analizzato, tramite dispositivo indossabile, l'attività fisica, la sedentarietà e il sonno di bambini e adolescenti con diabete di tipo 1, prima e durante un campo estivo strutturato. Ventitré partecipanti (età 13.33 ± 2.13 anni) seguiti dalla Pediatria endocrinologica dell'Ippokratio General Hospital (Salonicco, Grecia) hanno indossato per 7–8 giorni un Fitbit in condizioni di vita abituale e successivamente per 10 giorni durante un Diabetes Summer Camp organizzato in ambiente naturale, con tre sessioni giornaliere di attività fisica strutturata. I dati accelerometrici (passi, attività fisica leggera, moderata, vigorosa e sedentarietà) e di sonno (durata, durata totale dei risvegli notturni, efficienza) sono stati confrontati tra periodo pre-camp e periodo durante il camp. Al baseline, i giovani presentavano livelli di attività fisica moderata-vigorosa inferiori alle

raccomandazioni e un'elevata sedentarietà, con tempo di sonno ridotto e più frammentato. Durante il camp, si è osservato un incremento significativo dei passi giornalieri e del tempo in attività fisica leggera, moderata e vigorosa (tutti $p < 0.01$), associato a una riduzione significativa del tempo di sedentarietà ($p < 0.001$). La durata totale del sonno è diminuita, ma la durata totale dei risvegli notturni si è ridotta ($p = 0.005$) a parità di efficienza del sonno, suggerendo una migliore continuità. Analisi di regressione hanno mostrato associazioni significative tra tempo sedentario e durata delle veglie nel periodo prima del camp, e tra cambiamenti nei passi e continuità del sonno, evidenziando interazioni specifiche tra movimento e qualità del sonno in questa popolazione. Nel quarto studio, i dati di attività basata sui passi sono stati integrati con le dinamiche glicemiche negli stessi giovani con diabete di tipo 1 durante il camp. Trenta partecipanti (età 13.35 ± 1.89 anni) hanno effettuato misurazioni glicemiche tramite pungidito (sette controlli al giorno) e indossato dispositivi Fitbit che registravano i passi fatti al minuto per tutta la durata dei 10 giorni di camp. Per ogni intervallo tra due misurazioni glicemiche sono stati calcolati i passi accumulati. Nel dataset finale erano presenti, per ciascun timepoint, glicemia, carboidrati ingeriti, aggiustamenti insulinici e passi accumulati nell'intervallo tra una misurazione e l'altra. L'associazione tra passi e glicemia è stata analizzata tramite regressioni semplici, ANOVA, modelli lineari misti (LMM) e modelli additivi generalizzati misti (GAMM), mentre le capacità predittive sono state esplorate tramite modelli ARIMA. Le analisi hanno mostrato l'assenza di associazioni lineari significative tra passi e glicemia, mentre carboidrati ingeriti e aggiustamenti insulinici emergevano come predittori principali ($p < 0.001$). Tuttavia, nei modelli ARIMA individuali, l'aggiunta dei passi come regressore ha migliorato in modo significativo le prestazioni di previsione (riduzione di RMSE e MAE, $p = 0.001$ e $p = 0.003$), indicando che, pur non essendo fortemente associato alla glicemia, il comportamento motorio contribuisce all'aprevisione a breve termine delle traiettorie glicemiche. Il quinto studio ha infine valutato l'adattamento della frequenza cardiaca notturna (HR) durante il camp, utilizzando sensori fotopletismografici indossabili. Dopo uno studio pilota su due giovani adulti, utilizzato per definire criteri di qualità del segnale basati su valori di confidenza del dispositivo Fitbit Inspire HR, il monitoraggio è stato applicato a un sottogruppo di 23 adolescenti con diabete di tipo 1 (età

14.96 $\pm$ 1.63 anni) durante i 10 giorni di camp. Il segnale HR (campionamento ogni 5 secondi) è stato filtrato escludendo le osservazioni con bassa qualità, e per ciascuna notte è stata calcolata la media di HR nel segmento 00:00–08:00, abbinata a una misurazione glicemica notturna capillare tramite pungidito. L’andamento longitudinale della HR notturna è stato modellato tramite modelli lineari misti (LMM) includendo il giorno di camp come predittore fisso e intercette e pendenze casuali per partecipante. Il primo modello ha evidenziato un trend medio negativo (stima per giorno = -0.61 bpm/giorno, $p = 0.021$), con ampia eterogeneità inter-individuale ma prevalenza di pendenze negative, indicando un progressivo calo della HR notturna. L’aggiunta della glicemia notturna, sia come singola covariata, sia scomposta nelle componenti inter-individuale e intra-individuale, non ha migliorato significativamente l’adattamento dei modelli ($p \geq 0.25$), suggerendo che l’adattamento autonomico notturno osservato è sostanzialmente indipendente dalle variazioni glicemiche acute. Nel complesso, i risultati della tesi dimostrano che l’accelerometria e, conseguentemente l’actigrafia, rappresentano strumenti versatili e scalabili per la valutazione e l’integrazione dei comportamenti nelle 24 ore (attività fisica, sedentarietà, sonno) con parametri clinici e fisiologici in differenti popolazioni, che vanno da adulti sani impegnati in attività ecologiche a donne con incontinenza urinaria, fino a bambini e adolescenti con diabete di tipo 1, in contesti di vita reale e campi estivi strutturati. L’uso combinato di dispositivi indossabili, modelli statistici avanzati (LMM, GAMM, ARIMA) e indicatori clinici suggerisce che le tecnologie di *digital health* possano costituire un’infrastruttura concreta per interventi di prevenzione e gestione personalizzata, basati su dati continui e integrabili nella pratica clinica quotidiana e nei programmi di sanità pubblica orientati alla promozione di stili di vita salutari.

PAROLE CHIAVE:

Accelerometria; actigrafia; dispositivi indossabili; monitoraggio 24-ore; attività fisica; sedentarietà; sonno; frequenza cardiaca notturna; digital health; telemonitoraggio; riabilitazione; incontinenza urinaria; pavimento pelvico; diabete mellito di tipo 1; popolazioni pediatriche;

interventi multimodali; modelli predittivi; analisi longitudinale; prevenzione delle malattie croniche; sanità pubblica.

ABSTRACT

Non-communicable chronic diseases (NCDs) represent one of the major public health challenges and are closely linked to modifiable behaviors such as physical activity, sedentary behavior, and sleep. In this context, accelerometry and, consequently, actigraphy, integrated within *digital health* systems, enable continuous and objective monitoring of 24-hour behaviors (physical activity, sedentary behavior, sleep) and their integration with clinical and physiological indicators. For these reasons, the general objectives of this doctoral thesis were to: (i) analyze the feasibility and usefulness of wearable devices based on accelerometry in different populations and contexts; (ii) integrate accelerometry-derived signals with clinical, metabolic, and physiological measures; and (iii) explore the potential of such tools for promoting healthy lifestyles and managing chronic conditions. To address these objectives, five studies were conducted, each characterized by distinct experimental designs and increasing levels of complexity. In the first study, the physical activity modality of plogging, which combines running or walking with litter collection in natural environments, was characterized through wrist-worn accelerometry. Sixteen university students (22.50 ± 1.93 years) completed a 60-minute plogging session on a beach while wearing an accelerometer. Data were analyzed using different algorithms to classify activity levels (sedentary, light, moderate, and vigorous physical activity), estimate metabolic equivalents (METs), and assess energy expenditure. Three conditions were considered: no overload, total overload, and progressive overload, modeling the increasing weight of collected litter over the hour. Results showed that a session of plogging fell within the light-to-moderate intensity range in terms of METs, with most of the time spent in light and moderate activity and increased energy expenditure when the litter load was considered. This study provides an initial indirect physiological characterization of plogging and highlights its potential for physical activity promotion in natural settings. The second study integrated accelerometry within a rehabilitation program for women with urinary incontinence (UI). Twenty women aged 40–70 years with mild UI, assessed through a 48-hour pad test (<30 g/48 h), were invited to participate in a five-week multimodal exercise protocol. The intervention consisted of 14 supervised sessions combining

pelvic floor muscle exercises, intra-abdominal pressure control, postural and breathing work. Urinary loss (UL) through pad test, daily physical activity levels through wrist-worn accelerometry (>15 h/day of wear time in both phases), and pelvic floor symptom perception through the PFDI-20 questionnaire were assessed before (pre) and after (post) the intervention. Results showed a significant reduction in urinary leakage ($z = 3.92$, $p < 0.001$) and in total PFDI-20 score ($p = 0.007$). Light and moderate physical activity levels and steps per minute did not change significantly. The reduction in perceived symptom severity measured through the PFDI-20 exceeded the Minimal Clinically Important Difference (MCID) reported in the literature for both conservative and surgical interventions, indicating clinically meaningful improvement. At baseline, moderate physical activity was associated with pelvic floor symptom perception, whereas after the intervention this association was attenuated and no longer significant. Changes in UL and moderate physical activity both contributed to explaining improvements in symptom perception, indicating that multiple factors may underlie the observed clinical effects. These findings support the inclusion of wearable accelerometry to monitor physical activity behaviors within rehabilitation programs and suggest that improvements in pelvic floor symptoms do not necessarily require increases in total daily physical activity. The third study examined physical activity, sedentary behavior, and sleep in children and adolescents with Type 1 diabetes (T1D) through wearable devices, before and during a structured summer camp. Twenty-three participants (13.33 ± 2.13 years) followed by the Pediatric Endocrinology Unit of the Ippokratio General Hospital (Thessaloniki, Greece) wore a Fitbit device for 7–8 days in habitual living conditions and subsequently for 10 days during a Diabetes Summer Camp held in a natural environment, with three daily structured physical activity sessions. Accelerometry-derived variables (steps, light, moderate, and vigorous physical activity, sedentary time) and sleep metrics (duration, total nocturnal wake time, efficiency) were compared between pre-camp and camp periods. At baseline, youth exhibited moderate-to-vigorous physical activity levels below recommendations and high sedentary behavior, with shortened and more fragmented sleep. During the camp, significant increases in daily steps and light, moderate, and vigorous physical activity (all $p < 0.01$) were observed, accompanied by a significant reduction in sedentary time (p

< 0.001). Total sleep duration decreased, whereas total nocturnal wake time significantly decreased ($p = 0.005$) with no differences in sleep efficiency, suggesting improved sleep continuity. Regression analyses revealed significant associations between sedentary time and nocturnal wake time before the camp, and between changes in step counts and sleep continuity during the camp, highlighting specific interactions between movement and sleep quality in this population. In the fourth study, step-based activity data were integrated with glycemic dynamics in the same youth with T1D during the camp. Thirty participants (13.35 ± 1.89 years) performed seven daily fingerstick blood glucose measurements and wore Fitbit devices recording step counts per minute throughout the 10-day camp. For each interval between two glucose checks, accumulated steps were computed. The final dataset included blood glucose values, carbohydrate intake, insulin adjustments, and steps accumulated within each interval. The association between steps and glucose was explored through simple regressions, ANOVA, linear mixed models (LMM), and generalized additive mixed models (GAMM), while predictive capabilities were assessed through ARIMA models. Analyses showed no significant linear associations between steps and blood glucose, whereas carbohydrate intake and insulin adjustments emerged as main predictors ($p < 0.001$). However, in individual ARIMA models, adding steps as an exogenous regressor significantly improved forecasting performance (RMSE and MAE reduction, $p = 0.001$ and $p = 0.003$), indicating that although not strongly associated with concurrent glucose values, movement behavior contributes to short-term glucose trajectory prediction. The fifth study evaluated nocturnal heart rate (HR) adaptation during the camp using wearable photoplethysmographic sensors (PPG). A pilot study in two young adults was first conducted to define signal quality criteria based on Fitbit Inspire HR confidence values; monitoring was then applied to a subgroup of 23 adolescents with T1D (14.96 ± 1.63 years) over the 10 days. HR signals (5-second sampling) were filtered to exclude low-quality observations, and nightly mean HR in the 00:00–08:00 segment was computed and paired with a single nocturnal fingerstick glucose measurement. Longitudinal HR changes were modeled using linear mixed-effects models including day of camp as fixed predictor and random intercepts and slopes for participants. The first model showed a negative trend (-0.61 bpm/day, $p = 0.021$), with wide inter-individual

heterogeneity but a predominance of negative slopes, indicating progressive nocturnal HR reduction. Adding nocturnal glucose, either as single covariate or decomposed into between- and within-participant components, did not significantly improve model fit ($p \geq 0.25$), suggesting that nocturnal autonomic adaptation was substantially independent of acute glycemic variation. Overall, the findings of this thesis demonstrate that accelerometry and, consequently, actigraphy represent versatile and scalable tools for assessing and integrating 24-hour behaviors (physical activity, sedentary behavior, sleep) with clinical and physiological parameters across different populations, from healthy young adults engaged in ecological activities to women with urinary incontinence, and children and adolescents with T1D in real-world or structured settings. The combined use of wearable devices, advanced statistical models (LMM, GAMM, ARIMA), and clinical indicators suggests that *digital health* technologies may constitute a concrete infrastructure for prevention and personalized management interventions based on continuous data streams that can be integrated into clinical practice and public health programs aimed at promoting healthy lifestyles.

KEYWORDS:

Accelerometry; actigraphy; wearable devices; 24-hour monitoring; physical activity; sedentary behavior; sleep; nocturnal heart rate; digital health; telemonitoring; rehabilitation; urinary incontinence; pelvic floor; type 1 diabetes; pediatric populations; multimodal interventions; predictive models; longitudinal analysis; chronic disease prevention; public health.

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.

We never know how high we are
Till we are asked to rise
And then if we are true to plan
Our statures touch the skies -

The Heroism we recite
Would be a normal thing
Did not ourselves the Cubits warp
For fear to be a King.

Emily Dickinson

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ABBREVIATIONS

AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
ARIMA	Autoregressive Integrate Moving Average
ASAQ	Adolescent Sedentary Activity Questionnaire
AU	Arbitrary Unit
AVG	Average
BIC	Bayesian Information Criterion
BMI	Body Mass Index
BMI_z	Body Mass Index z-score
BMP	Beats Per Minute
CGM	Continuous Glucose Monitoring
cho	Carbohydrate
CORT	Cortisol
CRADI-8	Colorectal–Anal Distress Inventory-8
DHEA-S	Dehydroepiandrosterone Sulfate
EE	Energy Expenditure
GAMM	Generalized Additive Mixed Model
g	Grams
HFZ	Healthy Fitness Zone
HR	Heart Rate
HRV	Heart Rate Variability
IAP	Intra-Abdominal Pressure
ICC	Intraclass Correlation
ICS	International Continence Society

ins	Insulin adjustment
ISPAD	International Society of Paediatric and Adolescence Diabetes
IU	International Unit
Kcal	Kilocalorie
LIPA	Light Physical Activity
LMM	Linear Mixed Effect Model
LRT	Likelihood Ratio Test
MAE	Mean Absolute Error
MET	Metabolic Equivalent of Task
mg/dl	Milligrams per deciliter
ML	Maximum Likelihood
MPA	Moderate Physical Activity
MVPA	Moderate to Vigorous Physical Activity
NA	Missing value
PA	Physical Activity
PAEE	Physical Activity Energy Expenditure
PAQ-c	Physical Activity Questionnaire for Older Children
PFDI-20	Pelvic Floor Distress Inventory-20
PFMT	Pelvic Floor Muscles Training
POPDI-6	Pelvic Organ Prolapse Distress Inventory-6
PPG	Photoplethysmography
REML	Restricted / Residual Maximum Likelihood
RMSE	Root Means Square Error
SPM	Steps Per Minute
T1D	Type 1 Diabetes
UDI-6	Urinary Distress Inventory-6
UI	Urinary Incontinence

UL	Urinary Loss
VIF	Variance Inflation Factor
VMU	Vector Magnitude Unit
VO_{2peak}	Volume of Oxygen Peak
VPA	Vigorous Physical Activity
WD	Weekday
WE	Weekend
WHO	World Health Organization
YMCA	Young Men's Christian Association

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1. INTRODUCTION

1.Introduction

Non-communicable diseases (NCDs) represent the main cause of mortality and morbidity worldwide, responsible for more than 40 million deaths annually and accounting for approximately 74% of global mortality¹. These conditions, including cardiovascular diseases, cancer, chronic respiratory disorders, diabetes, and neurodegenerative diseases, are characterized by long latency, multifactorial etiology, and the absence of a contagious vector. They impose a substantial burden not only on individuals but also on healthcare systems and economies, affecting productivity, social stability, and quality of life^{2,3}. The increasing prevalence of NCDs in low- and middle-income countries, driven by population aging, urbanization, and lifestyle transitions, underscores the global inequities in prevention and management^{4,5}. Beyond their health implications, NCDs also contribute to economic losses exceeding trillions of dollars due to direct healthcare costs and loss of workforce productivity, posing a significant obstacle to achieving the United Nations Sustainable Development Goals⁵. The complex interplay between biological, behavioral, and environmental determinants underpins the risk of developing chronic diseases. Lifestyle behaviors, such as physical inactivity, unhealthy diet, tobacco use, alcohol consumption, and poor sleep, constitute major modifiable risk factors^{6,7}. These behaviors interact with environmental exposures including air pollution, urban noise, limited access to green spaces, and heat stress, which further exacerbate chronic disease risk⁸. A growing body of research highlights that both behavioral and environmental determinants must be addressed synergistically to mitigate NCDs effectively. In this context, the promotion of physical activity and adequate sleep, alongside healthy nutrition and stress management, represents an essential public health priority^{7,9}. However, despite strong evidence supporting behavioral modification, adherence to recommended activity and sleep guidelines remains low across all age groups, suggesting that traditional approaches to health promotion may be insufficient. In response, *digital health* technologies have emerged as transformative tools for the prevention and management of NCDs.

Digital health encompasses the use of connected technologies, sensors, and data-driven platforms to monitor, analyze, and promote individual and population health. Its integration into healthcare

has expanded rapidly, particularly during and after the COVID-19 pandemic, when remote care and telemonitoring became essential to maintain continuity of care for patients with chronic conditions^{10,11}. *Digital health* interventions enable continuous, real-time assessment of physiological and behavioral parameters, bridging the gap between clinical and everyday environments. They provide opportunities for early detection of risk patterns, personalized feedback, and improved patient engagement¹². Moreover, they empower patients and caregivers by promoting self-management and facilitating communication with healthcare providers, thereby enhancing treatment adherence and quality of life^{10,12}. Despite their promise, barriers such as user accessibility, data privacy, and regulatory complexity remain critical challenges for widespread adoption¹⁰. Among the diverse tools available, wearable devices, especially accelerometers, have become central in *digital health* research. Accelerometry provides objective, non-invasive, and continuous quantification of body movement, offering detailed information about the intensity, duration, and frequency of physical activity, sedentary behavior, and sleep^{13,14}. Building on accelerometry, actigraphy refers to the use of wearable accelerometer devices to infer behavioral states and patterns over extended periods of time. Unlike accelerometry, which provides raw physical measures of movement, actigraphy applies signal processing and scoring algorithms to classify and quantify behavioral domains such as physical activity, sedentary behavior, rest, and sleep. In this sense, actigraphy represents an interpretative layer on top of accelerometer-derived motion data, enabling the assessment of temporal organization of behavior in free-living conditions. Actigraphy is therefore not a distinct technology from accelerometry, but rather its application to behavioral and clinical monitoring^{15,16}. Over the past two decades, the evolution of accelerometer technologies has been remarkable: from uniaxial to triaxial sensors, from minute-level sampling to raw-signal data capture, and from laboratory-based use to free-living applications¹⁷. These advances have enabled more accurate measurement of physical behavior and its association with health outcomes. Nonetheless, differences in device placement, calibration, data processing algorithms, epoch lengths, and cut-points can influence comparability across studies, representing one of the main methodological challenges in accelerometry research^{13,17,18}. Methodological refinements and standardization efforts continue to evolve, with

growing attention to data quality, reproducibility, and interpretability^{18,19}. Comparative studies among devices, such as the ActiGraph and activPAL, have further clarified their respective strengths for quantifying activity and sedentary time, supporting evidence-based device selection for specific research aims¹⁹. Actigraphy extends beyond physical activity monitoring to encompass a broader “24-hour behavior” perspective that integrates movement, sedentary time, and sleep into a single health framework²⁰. This holistic approach provides a more comprehensive understanding of daily behavior patterns and their combined impact on cardiometabolic health. Actigraphy has also become a key instrument in large-scale epidemiological studies and intervention trials, enabling objective quantification of lifestyle behaviors and providing insight into the links between physical activity and chronic disease prevention^{14,18}. Importantly, accelerometer-based monitoring aligns with the paradigm of precision prevention, where continuous and individualized data enable tailored interventions based on each person’s behavioral profile^{11,12,14}.

At the physiological level, the relationship between physical activity and metabolic health has been elucidated through the identification of skeletal muscle as an endocrine organ. Contracting muscle releases cytokines and peptides, collectively termed myokines, such as interleukin-6 (IL-6), which mediate anti-inflammatory and metabolic effects throughout the body²⁰. This discovery has redefined the understanding of exercise as not merely mechanical activity but also a regulator of systemic homeostasis and disease modulation. Accumulating evidence demonstrates that regular exercise exerts therapeutic effects across a broad range of chronic diseases, from type 2 diabetes and cardiovascular disease to depression and cancer, reinforcing the concept of “exercise as medicine”²¹. As highlighted by clinical and translational studies, prescribing physical activity as a therapeutic intervention should be considered an integral component of chronic disease management and prevention^{9,21}. Despite growing consensus on the benefits of physical activity and the potential of *digital health* tools, their integration into everyday clinical practice and population health strategies remains incomplete. The challenge lies not only in validating measurement technologies but also in ensuring that collected data are meaningfully translated into

behavioral and clinical outcomes. Wearable-based monitoring must move beyond data collection toward active feedback loops that inform patients, guide clinicians, and adapt interventions dynamically^{10,12}. Furthermore, implementation in diverse populations, including children, older adults, and individuals with specific chronic conditions, requires context-sensitive validation and ethical considerations around data use. Within this evolving landscape, the present doctoral project aims to contribute to the growing field of *digital health* and behavioral monitoring by focusing on actigraphy as a tool for lifestyle assessment and intervention. Through a sequence of studies conducted across various populations and experimental contexts, the project explores methodological, clinical, and educational applications of actigraphy for understanding and promoting healthy behaviors. Through two preliminary studies, accelerometry was tested in diverse real-world scenarios, spanning from ecological movement assessment to clinical rehabilitation. This work supported the use of wearable monitoring as a versatile tool and informed the development of the central study. The central study, conducted during a Diabetes Summer Camp for children and adolescents with type 1 diabetes, represents the culmination of this research path. In this structured setting, continuous digital monitoring of physical activity, sedentary behavior, sleep, heart rate, and glucose levels allowed an integrated analysis of behavioral and physiological dynamics under real-world but controlled conditions. By combining insights from multiple disciplines, public health, physiology, data science, and behavioral medicine, this research seeks to advance the use of actigraphy and *digital health* technologies in the prevention and management of chronic diseases. The ultimate goal is to strengthen the scientific foundations and practical implementation of data-driven, personalized, and sustainable strategies for health promotion, disease prevention, and patient empowerment in the digital era.

2. EXPERIMENTAL DESIGN

2. Experimental Design

2.1 General rationale of the project

The doctoral project was conceived as an articulated and progressive research pathway aimed at thoroughly exploring the role of accelerometry and wearable sensors in monitoring lifestyle-related behaviors and integrating them with physiological and clinical indicators. All studies share the assumption that the objective analysis of movement represents a central element for understanding the behavioral determinants of chronic diseases and for developing personalized interventions based on the principles of *digital health*. The studies included in the project were not designed as isolated works but as successive phases of a unified methodological pathway. The project begins with the analysis of unconventional physical activities to assess the accuracy and adaptability of actigraphy in free ecological conditions and in healthy populations, then progresses to the application of this technology in clinical and rehabilitative contexts, and finally reaches the integrated observation of movement, sleep, heart rate, and metabolic parameters in a structured environment such as a Summer Camp. Alongside this observational component, a predictive modeling framework was developed to integrate accelerometric data into more complex systems applicable to clinical disease management. Taken together, the studies aim to build a multidimensional experimental model capable of demonstrating how actigraphy can be used reliably and across different health and prevention contexts.

2.2 Study 1 – Accelerometric analysis of plogging as an intermittent activity

The first study analyzed plogging, an emerging physical activity characterized by the continuous alternation between light running and litter collection, with the aim of describing its motor demands through accelerometry. The investigation was conducted in a natural environment, in a continuous one-hour session performed by healthy young adults monitored using an ActiGraph GT9X accelerometer worn on the non-dominant wrist. The choice to work in a non-standardized context made it possible to evaluate the ability of accelerometry to detect intermittent and irregular movement patterns. A relevant methodological aspect concerns the estimation of energy

expenditure, obtained by comparing three calculation conditions that included body weight, the total overload represented by the entire weight of the collected waste, and a progressive overload increasing throughout the activity. The combination of accelerometric data and load measurement highlighted the possibility of estimating energy expenditure in complex and non-linear activities, offering useful insights for subsequent studies based on less predictable motor behaviors.

2.3 Study 2 – Multimodal program for urinary incontinence and the role of daily physical activity

The second study placed actigraphy within a clinical and rehabilitative context, with the aim of evaluating the relationship between daily physical activity, urinary leakage, and symptom perception in women with mild urinary incontinence. The protocol involved a five-week multimodal intervention including pelvic floor exercises, breathing techniques, intra-abdominal pressure control, and postural activities. Participants were monitored through accelerometry for seven consecutive days before and after the program, while urinary leakage was quantified using a 48-hour pad test performed at home. Discomfort perception and symptom impact were assessed through a questionnaire. The results showed consistency between symptom reduction and increased moderate physical activity, suggesting that objective monitoring can provide complementary information compared to traditional measures. This study therefore strengthened the idea that actigraphy represents a useful tool also within rehabilitative pathways, adding value in quantifying behavioral changes associated with treatment.

2.4 Study 3 – Integrated monitoring of physical activity, sedentary behavior and sleep in the Diabetes Summer Camp

The third study represents the core of the doctoral project and focuses on minute-by-minute monitoring of motor behavior and sleep in children and adolescents with type 1 diabetes, comparing one week of daily life with ten days spent in a highly structured summer camp. Data were collected through Fitbit Ace 3 or Inspire HR devices, which allowed continuous recording of steps, activity intensity, sedentary time, sleep duration, and nighttime awakenings. Participants were also assessed through fitness tests and questionnaires on motor and sedentary habits. The

camp, characterized by a daily schedule including three physical activity sessions and numerous walking-based transfers, resulted in a marked increase in moderate and vigorous physical activity and a significant reduction in sedentary behavior compared to the preceding phase. Although sleep duration decreased, sleep efficiency, as indicated by the duration of nighttime awakenings, showed a significant reduction, suggesting potential benefits of physical activity on sleep quality during the camp.

Methodological note on data completeness

Across the three studies conducted during the Diabetes Summer Camp, the number of participants included in the analyses varies according to the availability and completeness of the data collected. Not all participants had the same complete datasets for the different purposes of the project. For the comparison between motor behavior and sleep in the pre-camp and camp phases, only those subjects with continuous recordings available for both periods were included. For the combined analysis of physical activity, sleep, glycemia, carbohydrates, and insulin during the camp, a larger sample was considered, including all participants for whom these data were complete and technically valid. Finally, the study on nighttime cardiac adaptation involved a different number of participants, as only some of the Fitbit devices used were equipped with continuous heart rate monitoring, and additional exclusions were necessary to ensure signal quality and continuity. The variability in analyzed samples reflects the nature of wearable-sensor-based projects and aligns with common practices in digital research, where data completeness may differ across individuals. All analyses were conducted using a complete case analysis approach, including only fully available data for the variables of interest.

2.5 Study 4 – Integration of accelerometric signals into glycemic prediction models

The fourth study used the data collected during the camp to investigate the integration between motor behaviors and metabolic dynamics. Through statistical prediction models, two approaches to forecasting glycemic trends were compared: one based exclusively on ingested carbohydrates and insulin adjustments, and another enriched by the number of steps recorded within the temporal

windows corresponding to glycemic measurements. The inclusion of accelerometric data did not show a direct association with glycemic values, but it significantly improved model accuracy in terms of mean absolute error and root-mean-square error. This suggests that physical activity, although not a linear predictor of glycemia, contributes to a better representation of metabolic regulation dynamics during childhood and adolescence.

2.6 Study 5 – Nocturnal cardiac adaptation during the camp

The fifth study analyzed variations in nighttime heart rate recorded through Fitbit PPG sensors, with the aim of evaluating physiological adaptation to daily physical activity. Over the ten days of camp, a progressive reduction in resting nighttime heart rate was observed, interpreted as an indicator of improved autonomic recovery and cardiovascular efficiency. This analysis added a physiological layer to behavioral monitoring, showing how lifestyle changes during the camp were reflected not only in activity levels but also in cardiac parameters associated with overall fitness status.

2.7 Methodological integration across studies

Overall, the five studies share an approach based on complementarity between accelerometric data and other objective or subjective measures. The first two studies enabled the evaluation of accelerometry in uncontrolled environments and clinical settings; the third represented the first of the three central studies, with continuous 24-hour monitoring in a structured setting; the fourth showed how such data can be used in predictive models potentially useful for diabetes management; and the fifth integrated advanced physiological signals to evaluate cardiac adaptation processes. This progression made it possible to explore the versatility of actigraphy across different domains and to highlight its role in *digital health* as a tool capable of combining behavioral observation, physiological analysis, and modeling.

2.8 Conclusion of the experimental design

The experimental design of the project integrates observational, interventional, and predictive approaches, using wearable technologies to investigate human behavior and some physiological determinants of health in a multidimensional manner. The coherence of the scientific pathway demonstrates that accelerometry is a reliable and scalable method capable of providing useful information for the prevention of chronic diseases and for the development of personalized interventions based on continuous and real-world data.

3. STUDY 1: Plogging As An Intermittent Activity For Environmental Clean-Up: Estimating Energy Demand And Physical Activity Intensity Of One Hour Session

3.1 Introduction

The climate change, defined as “a phenomenon referring to the long-term changes occurring in Earth’s climatic variables” by the United Nations²², represents one of the main scientific, political, and social topics of discussion of the last years. The impact of the climatic crisis involves several dimensions of human life, including health, biodiversity, potable water availability, and agricultural systems, and is forcing entire populations to leave their places for safer and more habitable areas²³. To this picture, the growing problem of plastic pollution adds up. The production, transport, littering, and fragmentation of plastic waste significantly contribute to greenhouse gas emissions, whereas the climatic change itself accelerates the degradation and diffusion of microplastics in the environment, creating a vicious circle between climatic crisis and pollution²⁴. In this context, the attention to practices which promote environmental sustainability and ecosystem protection is quickly growing. Initiatives of waste collection and community actions represent efficient approaches to counter pollution and raise awareness among populations. Among these, *plogging* has established itself as a practice which combines movement and environmental engagement, becoming a symbol of a sport activity with high positive ecological impact²⁵. It is widely demonstrated that practising regular physical exercise reduces the risk of cardiovascular, metabolic, and psychological diseases, favouring improvements in cardiorespiratory capacities, muscle functions, and mental health²⁶. Intermittent dynamic activities, which combine various movements and intensity changes, represent efficient ways to improve energy expenditure (EE) and promote active lifestyles. Recent evidence confirms that these exercise modalities, characterized by short but repeated increments of intensity, can induce strong metabolic and cardiorespiratory adaptations, enhancing parameters like Volume of Oxygen peak (VO_{2peak}), insulin sensitivity, and lipid profiles, even with short-duration sessions compared to continuous activity²⁷. Further benefits emerge when physical activity is practiced in natural environments. The so-called green exercise is associated with better psychophysiological profiles, anxiety and stress reduction, increased vigour, and perception of well-being compared to exercises practised in urban or indoor contexts²⁸. The exposure to nature seems to facilitate behavioural adherence and the subjective positive experience during the

practice of physical activity. Recent studies indicate that natural environments may also influence the neuroendocrine responses to exercise. In particular, Di Blasio et al. (2022) showed that physical activity sessions performed in contexts combining green and blue elements determine lower levels of cortisol and higher levels of Dehydroepiandrosterone Sulphate (DHEA-S), with a consequent reduction in the CORT/DHEA-S ratio, compared to indoor exercise, even with the same effort²⁹. *Plogging*, born in Sweden in 2016, combines walking, jogging, or running with waste collection. The word *plogging* derives from the Swedish words *plocka upp*, which means picking up, and *jogga*, which means jogging^{25,30}. This activity integrates two fundamental aspects of the current international debate: health promotion through the practice of physical exercise and environmental protection. Recent studies show how *plogging* has a relevant educational role, favouring ecological consciousness, civic sense, and active participation in school and university communities³¹. Close to the environmental and physical benefits, *plogging* shows potential positive psychological effects. The combination between movement, contact with nature, and prosocial behaviour can increase personal satisfaction, the sense of self-efficacy, and well-being perception³². The evidence reached in studies related to *plogging* confirms this setting: students who participate in this activity develop a greater connection with nature, a higher environmental consciousness, and a stronger perception of ecological self-efficacy³¹. Moreover, *plogging* incorporates components that favour the development of empathy and cooperation, elements known to increase well-being and personal satisfaction^{33,34}. Taking care of the environment represents an action with social value, able to generate positive feelings and a sense of purpose which maintains individual motivation³¹. Although the growing interest in *plogging* as a practice which integrates physical activity and environmental engagement, scientific literature is limited. The available studies focus mainly on educational, psychological and environmental aspects of this sport, while evidence related to physiological and EE parameters associated with its practice is missing. In particular, objective analyses on movement pattern, physical activity levels, Metabolic Equivalent of Tasks (METs) and EE as well as evaluations which give importance to the progressive load generated by the transport of the rubbish during the session are missing. This gap limits the possibility to understand whether *plogging* could be considered a kind of physical

exercise with potential benefits on the metabolic plane and on health. On the basis of the nature of this sport, characterized by an intermittent structure, by continuous change of movement (walking, jogging, stops, bending, and squatting) and by the growing overload represented by the waste collected during the session, we hypothesize that (i) *plogging*, cause its intermittent structure, could be placed between light and moderate physical activity intensity; (ii) EE increases significantly when we consider the load of waste collected; (iii) this discipline could represent a kind of physical activity able to produce metabolic and physiological benefits, comparable to other intermittent exercises. In light of the above, the aim of the present study is to analyse the movement pattern expressed during a one-hour *plogging* session performed in a natural environment (beach) and to objectively quantify, through wrist-worn accelerometry, key indirect physiological parameters such as METs, EE (kcal), and the time spent in different physical activity intensity domains (Light, Moderate and Vigorous Physical Activity). Furthermore, the study seeks to evaluate these variables under three distinct methodological conditions: first, without considering the load of the waste collected; second, by including the total load accumulated at the end of the session; and finally, by estimating a progressively increasing load proportionally distributed across the entire duration of the activity. This approach enables a first characterisation of *plogging* and allows to understand how both its intermittent nature and the additional load generated by the waste collection may influence the energetic demands of this discipline.

3.2 Materials and Methods

3.2.1 Study design

The study was structured as a cross-sectional observational protocol performed in a natural outdoor environment, in which physiological-derived parameters and movement-related variables were continuously monitored during a single *plogging* session.

3.2.2 Participants

Sixteen university students, twelve males and four females (age: 22.50 ± 1.93), were recruited for the study. The exclusion criteria involved the absence of injuries or any clinical conditions at the time of the protocol, and not being under pharmacological treatment. Participation was voluntary and an informed consent was signed by each participant before the participation. Table 1 shows in details the sample characteristics.

Table 1. Anthropometry and demographics of the participating students.

Variable	All participants (<i>n</i>=16)	Males (<i>n</i>=12)	Females (<i>n</i>=4)
Age (y)	22.50 ± 1.93	22.33 ± 0.77	23 ± 4
Height (m)	1.72 ± 0.10	1.76 ± 0.07	1.59 ± 0.01
Weight (kg)	67.37 ± 11.05	56 ± 10.10	71.16 ± 8.72
BMI (kg/m^2)	22.59 ± 2.32	22.81 ± 1.82	21.92 ± 3.75

Values expressed as mean $\pm$ Standard Deviation (SD); y: years; m: meters; kg: kilograms; BMI: body mass index.

3.2.3 Procedures

The participants arrived at the experiment site in the morning at 9:00. The experiment took place in Vasto, Abruzzo (Italy), on a stretch of flat beach under clear weather conditions, with a temperature of 15 degrees and humidity of 78%. Upon arrival, participants were equipped with a trash bag and work gloves to pick up the litter from the ground. Participants practised one hour of a *plogging* session wearing an accelerometer *ActiGraph GT9X Link+* (Pensacola, FL, USA) on their non-dominant wrist at a 30 Hz frequency, to estimate physical activity time at different intensities and the EE in kilocalories (kcal) and Metabolic Equivalent of Tasks (METs). The choice to place the device on wrist and not on hip, as more common, was due to the continuous and repeated bending movements performed during the entire activity, which could had modified the correct device placement on hip and possibly recorded incorrect data. Moreover, specifically, the device was applied on non-dominant wrist. This choice was due to the possible overestimation of the movements performed during the waste collection from the ground with their dominant

hand. The amount of the waste collected by each participant was weighted at the end of the plogging session using an electronic dynamometer and then summed to calculate the total amount of waste collected during the session.

3.2.4 Data Processing and Analysis

Accelerometer data were downloaded using ActiLife v6.13.4 (Pensacola, FL, USA) with 60-second epochs, as required when applying count-based algorithms validated for wrist placement. Wear time was verified using the Choi (2011) algorithm³⁵. Although this algorithm is commonly applied in multi-day free-living protocols, in the present controlled 60-minute session it was used to confirm continuous device use and to detect potential non-wear periods or artefactual zero-count windows, ensuring that all epochs included in the analysis reflected actual activity data. Physical activity intensity classification was performed using the Montoye (2020) cut-point algorithm³⁶, the only validated model for wrist-worn accelerometers on healthy adult population. This method converts raw acceleration into Vector Magnitude Units (VMU) and classifies each epoch into sedentary behavior (0–2860 counts), light physical activity (LIPA) (2861–3941 counts), moderate physical activity (MPA) (3942–5613 counts), or vigorous physical activity (VPA) (>5613 counts). EE and METs were estimated using the standard ActiLife algorithms (Freedson Combination and Freedson Adult)³⁷, which are validated for hip-worn devices and incorporate body weight into the calculations. The Freedson Adult model is based on a single regression equation, whereas the Freedson Combination algorithm switches between two prediction approaches depending on the activity count level, integrating the Work–Energy Theorem at lower intensities and the Freedson regression at higher intensities. Although these algorithms were originally developed and validated for hip-worn accelerometers³⁸, evidence indicate that ActiGraph devices can provide acceptable estimates of total physical activity energy expenditure (PAEE) even when worn on different anatomical sites³⁹. Nonetheless, studies directly comparing wrist and hip placement⁴⁰, document activity-specific bias and a tendency toward overestimation when the device is worn on the wrist. For this reason, we considered the results appropriate in this protocol with caution, acknowledging this limitation. A first estimation was

performed considering only the body weight of the participants, treating the activity as unloaded. Since plogging involves carrying an increasing amount of collected litter, two additional conditions were created. First, EE and METs were recalculated by adding a fixed overload of 16 kg to each participant's body weight. This value corresponds to the individual share of the total amount of litter collected by the group (256 kg), obtained by dividing it equally among all participants. Second, to approximate a realistic progression of the carried weight, a time-dependent overload was created by proportionally distributing the total collected weight across the 60-minute session under the assumption of gradual linear accumulation (Figure 1). In this model, the load assigned to each epoch increased progressively from 0 kg to the individual final load of 16 kg, corresponding to each participant's equal share of the total litter collected. Each epoch was assigned an incrementally higher load, and EE and METs were recalculated for every interval. EE values were summed across epochs, whereas METs were averaged to obtain a session-level estimate. Descriptive statistics were performed using JASP 0.17 (Amsterdam, Netherlands) and normality of distribution was assessed using the Shapiro–Wilks test, with significance set at $p < 0.05$.

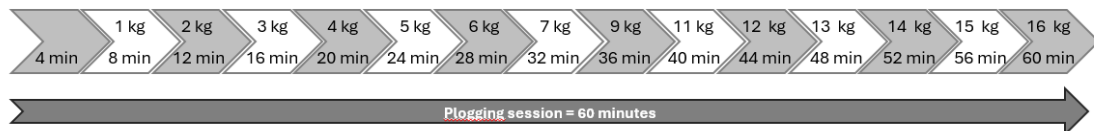


Figure 1. Progressive load distribution applied across the 60-minute plogging session.

3.3 Results

One hour of plogging on the beach was classified, on average, as an activity between light and moderate intensity. Participants spent a mean of 28.68 minutes in LIPA and 20.18 minutes in MPA. The accelerometers also recorded a mean of 11.12 minutes of sedentary time and an average of 2139 steps. Minutes spent in VPA were not reported because the activity did not reach the minimum count threshold required to classify VPA. Details are shown in Table 2. Since the physical activity intensity levels are determined exclusively by accelerometer counts, these values

remained identical across all load conditions (no overload, total overload, and progressive overload).

Table 2. Minutes spent in each physical activity intensity category and step counts recorded during the plogging session.

Variable	Intensity classification (counts-based)
Sedentary (min)	11.12 $\pm$ 5.97
LIPA (min)	28.68 $\pm$ 8.28
MPA (min)	20.18 $\pm$ 9.80
Steps (counts)	2139.75 $\pm$ 349.36

Values expressed as mean $\pm$ SD; min: minutes; LIPA: Light Intensity Physical Activity; MPA: Moderate Physical Activity.

Regarding EE and METs, considering only participants' body weight, the mean EE and METs were 174.34 kcal and 2.57 METs, respectively. When the total overload corresponding to the weight of the collected waste was added to body weight, EE increased to 254.14 kcal and METs to 3.06. Finally, when applying the normalized and progressive overload, EE was 216.47 kcal and METs were 2.85. Across all three conditions, the activity fell within the light-to-moderate intensity range. Details are shown in Table 3.

Table 3. EE and METs calculated in the three load conditions (without overload, with total overload, and with progressive overload).

Variable	Without overload	With total overload	With progressive overload
EE (kcal)	174.34 $\pm$ 62.01	254.14 $\pm$ 73.34	216.47 $\pm$ 66.78
METs	2.57 $\pm$ 0.58	3.06 $\pm$ 0.58	2.85 $\pm$ 0.57

Values expressed as mean $\pm$ SD; EE: energy expenditure; kcal: kilocalories; METs: Metabolic Equivalent of Task.

3.4 Discussion

This study provides the first indirect physiological characterization of *plogging* in a real-world context (beach) showing that a session of one hour is placed between light and moderate intensity, with most of the time spent in LIPA followed by MPA, and an average of METs in the range 2.5-3.0. The introduction of total overload condition linked with waste collected increased the EE compared to freehand condition, while the model with progressive overload showed intermediate estimates but plausible in an ecological point of view, because the load carried grows during the activity. As expected, the minutes spent in different levels of physical activity don't change between the conditions, being determined by counts³⁶, but EE and METs resulted sensitive to overload, consistently with the increase of mechanic and energetic demand. The research on *plogging* was above all focused on educational, psychological and environmental aspects²⁸, while objective data on energetic demand and movement pattern miss. Our results partially fill this gap, suggesting that *plogging*, for its intermittent nature (alternance of walking/jogging/stops/bending/squatting), falls within the range light-to-moderate, but with EEs which increase when the waste load carried is considered. This is coherent with the evidence that intermittent exercises could induce cardiorespiratory and metabolic adaptations equal or major to continuous activity, depending on design and population^{27,41}. Even it is not the goal to quantify the chronic adaptations, the *plogging* framework as intermittent activity at low-to-moderate load is relevant for physical activity promotion programs in students and young adults. Performing activity in natural environments can favour psychophysiological profiles more favourable compared to indoor or urban contexts²⁸, with possible effects on stress and well-being²⁹. The recent literature on green exercise shows heterogeneous results. Some reviews show significant benefits on mental well-being and physiological parameters in the short term^{42,43}, while others underlined a limited evidence or different quality when outdoor and indoor activities at the same intensity are compared⁴⁴. In our case, the coastal environment and the prosocial element of the clean-up could increase the engagement and the perception of enjoyment, favouring behavioural adherence, aspects to verify with psychometric measurements in future researchers. The EE and METs estimates were obtained with two algorithms implemented in ActiLife software³⁷. These

models were originally validated on hip, but recent studies show that, even they could provide acceptable estimates of total PAEE in healthy adults against criteria as indirect calorimetry, specific activity bias emerge as well as placements issues⁴⁰. In particular, comparing wrist vs hip in free-living conditions indicates the tendency to overestimate EE on wrist compared to hip³⁹. For this reason, we interpreted the estimates with caution and create three conditions (without overload, with total overload, with progressive overload), to provide a plausible range to energy demand. This approach gives response also to the need to represent the growing load of *plogging*, conceptually relevant. A strong point is the original modelling of the load, indeed, the comparison between freehand condition with total fixed overload and progressive overload allowed to isolate the effect of the waste transport on EE/METs, maintaining steady the counts to the intensity. Moreover, the natural real-world context (beach) increases the environmental friendliness on the measurements and the possibility to develop initiatives of public health which combine movement and sustainability.

3.5 Limitations

Despite the novelty of the topics covered in this study, several limitations must be mentioned. First, the accelerometer placement on the non-dominant wrist: *plogging* involves both arms with a possible movement overestimation. Second, the absence of an algorithm validated for the wrist to estimate EE/METs: the hip-based equations can over/underestimate (even with large variability between activities). Third, the absence of direct physiological measures (e.g., heart rate, Volume of Oxygen (VO₂)), which could have allowed a convergent pattern validation. Fourth, the duration of the activity was limited to one hour. Lastly, the small sample size of university students reduces the generalizability to other populations. Our results suggest that *plogging* is an intermittent exercise characterized by light-to-moderate intensity, accessible and potentially scalable to university and community programs, with a realistic increase in energy cost with the overload. Practical applications include sessions programmed based on short but frequent durations, integration with heart rate and VO₂ to improve the estimation of physiological cost, comparison with traditional walking/jogging at the same duration, monitoring of real load minute-by-minute

(intermediate litter-collected weighing or smart sensors) to refine the EE models. Considering the unique combination of environmental benefits, prosocial engagement and sustainable intensity, plogging deserves controlled studies in the medium term to evaluate cardiometabolic, psychological and behavioural outcomes.

3.6 Conclusions

In summary, a single session of plogging on the beach is configured as an intermittent activity at low-to-moderate intensity, with EE that increases with the overload carried. The progressive overload modelling provides a more ecologically valid estimation of the energy demand compared to bodyweight only. In light of the methodological limitations of the hip-based algorithms applied to the wrist and the absence of direct physiological measures, our results should be interpreted as coherent estimates of the activity performed, useful to design real interventions that combine health and sustainability.

**4. STUDY 2: Effects of a Multimodal Training
Program for the Management of Urinary Incontinence
and Physical Activity Levels on Symptom
Perception and Urine Loss**

4.1 Introduction

Urinary incontinence (UI), defined as a condition characterized by the involuntary loss of urine, is caused by a dysfunction of the pelvic floor muscles. Although it can occur in both sexes, it is much more frequent in women, especially after pregnancy or with aging⁴⁵. This condition is associated with comorbidities which include neurological, psychological, and cardiovascular problems⁴⁶, and with a decrease in quality of life and productivity⁴⁷. A recent scoping review showed that UI is potentially associated with sedentary behaviour in women⁴⁸. Longer time spent sedentary (64% of awake time) is strongly associated with severe UI in adult women⁴⁹. Moreover, women with UI were found to spend approximately 8 to 11 hours per day in sedentary activities, significantly more than their counterparts without UI⁴⁸. It is widely recognized that physical activity, and especially regular exercise, promotes overall health, exerting favorable effects across multiple physiological systems and functions of the body⁵⁰. Specifically, the practice of moderate physical activity (MPA) seems to be more beneficial compared with light physical activity (LIPA) in reducing the risk of mortality⁵¹. On the other hand, lower step count, shorter duration of LIPA and MPA are significantly associated with UI disorders⁵². Although it was recognized that light to moderate physical activity (e.g., brisk walking) can reduce the risk of UI development and, consequently, the associated disturbances⁵³, it remains unclear how long MPA should be performed each day and whether it could influence urinary disorders and perception. Previous studies have explored the relationship between MPA and pelvic floor disorders, but most based on subjective measures, either for physical activity or for urinary symptoms^{52,53}. Consequently, the association between objectively measured activity levels and perceived pelvic floor disturbances remains unclear. In this context, UL represents a direct physiological indicator of pelvic floor dysfunction, whereas MPA reflects behavioral patterns that may modulate both function and disorders perception. Many studies have shown a significant reduction in urinary loss (UL) when interventions of pelvic floor muscles training (PFMT) were performed for a minimum of four weeks⁵⁴, but most of the studies on pelvic floor rehabilitation have focused on the Kegel method, which focuses on isolated contraction and release of the pelvic floor muscles⁵⁵. However, more recent approaches have included functional exercises designed to reduce intra-

abdominal pressure (IAP) through improved posture and breathing control^{56,57}. Managing the IAP could help women with UI in reducing strain on the pelvic floor muscles and UL⁵⁸. Although there is evidence that reducing IAP can positively affect UI⁵⁹, to the best of our knowledge, there is a lack of studies investigating the effects of multimodal interventions where posture, breathing patterns, core ability, and overall fitness are improved through strategies designed to manage IAP within safe limits. Building on this gap, we asked whether an original multimodal training protocol integrating these components into a structured intervention could be more effective for women with UI. Furthermore, it is unclear whether UL reduction after PFMT leads to improvements in perceived pelvic floor disorders and what role daily activity level plays. We hypothesize that reductions in UL as well as MPA, both measured objectively, will be significant predictors of improvements in perceived pelvic floor disturbances from pre to post treatment. The goal of this study was to evaluate how UL and time spent in MPA affect subjective pelvic floor disturbances in 20 adult women affected by UI who participated in a five-week multimodal exercise intervention.

4.2 Materials and Methods

4.2.1 Participants

The study included 23 women aged between 40 and 70 who were invited to participate in a five-week exercise protocol. Participants were affected by stress and mixed UI (3, 17, respectively). According to Hellstrom and colleagues thresholds⁶⁰ for the 48-h pad test, all women presented mild incontinence (urine loss < 30 g over 48 h). Fifteen participants were post-menopausal, four were peri-menopausal, and one was pre-menopausal. No participant reported previous PFMT), prior pelvic floor or urogynecological surgery, diabetes, or the use of diuretics or medications known to influence urinary symptoms. A power analysis was conducted using G*Power (Version 3.1.9.4), assuming a paired-sample t-test (pre–post). Because the literature provides no consistent or transferable effect-size estimates for pre–post changes in 48-hour pad-test urine loss, we relied on studies reporting medium-to-large improvements in pelvic-floor-related questionnaire outcomes and physical function parameters in similar conservative-intervention contexts^{52,61}.

Accordingly, we adopted a pragmatic effect size of Cohen's $d = 0.7$, with $\alpha = 0.05$ and power = 0.80, a minimum sample of 15 participants was estimated. The inclusion criteria were being able to perform normal physical activity (i.e. no physician-diagnosed restrictions that would prevent them from doing everyday tasks), the diagnosis of urinary incontinence and/or uterine prolapse, and inclusion of both premenopausal and postmenopausal women. The exclusion criteria included the presence of acute medical issues (pain, injury, surgery at the time of the study), being pregnant, being an expert practitioner of a sport or discipline. Three women were excluded from the group, two of them due to incomplete accelerometer data and one because she was unable to follow all the instructions given during the training sessions due to a hearing impairment. In the end, the study sample included 20 women. Before starting, the participants gave their consent to the study signing the informed consent forms.

4.2.2 Procedure

The participants were evaluated in two time points: before the start of the protocol (pre) and at the end of the treatment (post). The evaluation tests consisted of objective measurements of UL and physical activity levels, as well as the administration of a questionnaire related to pelvic floor disorders. Evaluations were conducted using the same procedures, in the same environment and under consistent operating conditions to minimize external variables. Figure 2 shows the timeline of the procedure. To ensure independence from the funding institution, the co-author employed by the industrial partner contributed only to the initial conceptualization and administrative coordination of the project, without access to data or involvement in data collection, analysis, or interpretation. Academic authors retained full control over all scientific procedures.

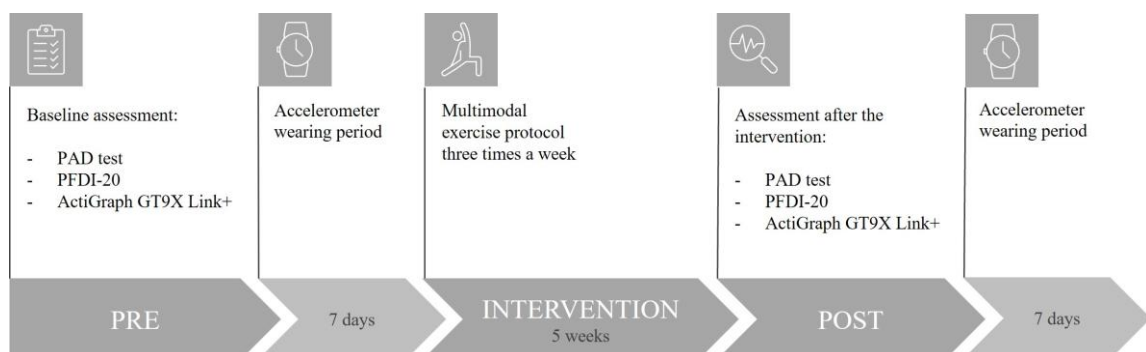


Figure 2. Procedure Timeline.

4.2.3 *Urinary incontinence*

Urinary loss (UL) was assessed using a 48-hour Pad test, which quantifies leakage by calculating the weight absorbent pads (a sanitary napkin) ⁶². The Pad test is a commonly used tool in continence research. According to the International Continence Society (ICS), a fully standardised protocol exists only for the 1-hour pad test, while for longer monitoring periods (24–72 hours) the ICS has not established a formal protocol ⁶³. Procedures for long-term pad testing described in the literature indicate that 24–48-hour assessments should be performed in real-life conditions: participants go about their usual daily activities and maintain their habitual drinking patterns ⁶⁴. Following these recommendations, in the present study the 48-hour pad test was carried out at home, the participants were instructed to maintain their normal routines and fluid-consumption habits throughout the test period. For descriptive purposes, incontinence severity was categorised using the thresholds proposed by Hellström et al. (1993) ⁶⁰, according to which total urine loss below 30 g over 48 hours is considered mild.

4.2.4 *Physical activity*

To objectively evaluate physical activity levels and sedentary behavior, wearable electronic devices (ActiGraph GT9X Link+, Pensacola, FL, USA) were used. The devices were initialized at a frequency of 30 Hz using ActiLife software (version 6.13.4, Pensacola, FL, USA). Participants wore the devices on the wrist for seven consecutive days to maximise wear-time compliance and user comfort, consistent with evidence that wrist-worn accelerometers improve adherence compared to waist placement ⁶⁵. Non-wear time was identified using the algorithm proposed by Choi ³⁵, which defines non-wear periods as intervals of at least 90 consecutive minutes of zero counts, allowing for up to 2 minutes of counts between 0 and 100. A valid day was defined as at least 10 hours of wear time, and participants with a minimum of four valid days were included in the analyses. At the end of the monitoring period, the devices were returned, and data were downloaded using ActiLife v6.13.4 software (Pensacola, FL, USA) with a 60-second epoch length. To classify time spent in different physical activity intensity levels, the algorithm

created by Montoye was used ³⁶. The Montoye algorithm was selected because it provides validated cut-points for wrist-worn accelerometers in free-living adults, enabling classification of physical-activity intensities using vector movement, known as the Vector Magnitude Unit (VMU) which is used to identify the cut-points required to discriminate between different physical activity intensities. The VMU is a composite measure of physical activity intensity, calculated by combining the accelerations on the three axes (X, Y, and Z), and provides a single value that represents the magnitude of movement, independent of direction. Counts between 0 and 2860 are classified as sedentary behavior; between 2861 and 3941 as light physical activity (LIPA); between 3942 and 5613 as moderate physical activity (MPA); and values above 5613 as vigorous physical activity (VPA). The minimum threshold to classify an activity as moderate-to-vigorous physical activity (MVPA) is 3942 counts.

4.2.5 Pelvic floor disorders

The Italian version of the Pelvic Floor Distress Inventory (PFDI-20) ⁶⁶ was used to evaluate pelvic floor disorders. The PFDI-20 is a tool made up of 20 items, created to evaluate the presence and the severity of the issues associated with pelvic floor disorders in women. The questionnaire consists of three sections, each of which explores a different symptom field, including the Pelvic Organ Prolapse Distress Inventory (POPDI-6), which consists of 6 items related to pelvic organs prolapse, the Colorectal-Anal Distress Inventory (CRADI-8), made up of 8 items that investigate gastrointestinal issues, and the Urinary Distress Inventory (UDI-6), made up of 6 items related to urinary disorders (i.e. incontinence, urgency and frequency). For each item, if the disorder was present, the participant indicated the level of distress caused (on a range from 1 to 4) and the score of each section was standardized to a 0-100 scale multiplying the average score by 25. The total score was given by the sum of the three sections (0 to 300), where higher scores indicated that the pelvic floor disorders had a greater impact on their quality of life.

4.2.6 Intervention

The study included a five-week intervention with three weekly 60-minute sessions. The protocol employed was based on a multimodal approach incorporating exercises aimed at improving core

stability and protecting the pelvic floor by managing IAP. This method was focused on the following key principles:

- Expiratory control: initiating every movement during exhalation to properly engage the transversus abdominis and the pelvic floor.
- Spinal elongation: avoiding compressions or postural collapse.
- Neutral posture: maintaining a neutral pelvis position, avoiding forced retroversion or anteversion.
- Perineal protection: performing exercises that do not create downward pressure.

The protocol did not aim to directly reduce intra-abdominal pressure, as in hypopressive training⁵⁶, but rather to optimize pressure management by promoting anticipatory activation of the pelvic floor muscles and transversus abdominis during functional movements, and by minimizing excessive trunk flexion that may increase downward pressure on the pelvic floor. The first week focused on education about breathing, posture, and pelvic floor awareness, with exercises performed both in seated and standing positions. In the second week, the same exercises were repeated in new positions, such as supine and quadruped, with the introduction of small equipment and self-massage of the pelvic floor and abdominal wall using small balls. During the third week, the program was enriched with exercises to strengthen the abdominal muscles, introducing McGill's "Big Three"⁶⁷ and glute exercises, including single leg support movements. In the fourth and fifth weeks, the exercises from the earlier weeks were performed in a more dynamic and complex manner, with the goal of transferring the learned patterns into everyday life. To facilitate the integration of the protocol's principles into the participants' daily routines, the first sessions also included educational content on pelvic floor and urogenital anatomy and physiology. Participants received guidelines on healthy habits that support urinary continence, as well as behaviors to avoid in order to reduce excessive intra-abdominal pressure. After these initial sessions with a more theoretical framework, participants were instructed on how to apply the same principles at home during everyday movements, with the aim of preventing abdominal over-pressures and minimizing stress on the pelvic floor. The sessions were delivered by qualified

professionals, graduates in Exercise and Sport Sciences with specialization in Preventive and Adapted Physical Activity. Before the start of the study, all instructors attended coordination meetings to ensure standardized and reproducible delivery of the multimodal protocol. Each class was supervised by one lead instructor demonstrating the exercises, supported by one or two assistant instructors who moved among participants to monitor performance and provide individualized corrections. To optimize intervention fidelity and ensure participant safety, group sizes were intentionally kept small (6–9 women per session), allowing for close supervision and continuous feedback.

4.2.7 Statistical Analysis

For the statistical analysis, JASP software (JASP Team 2024. JASP Version 0.19.3) was used. Descriptive statistics were calculated for age, body mass index (BMI), and all outcome measures, and the Shapiro-Wilk test was conducted to assess the normality of the data distribution. Based on the results of the normality test, paired Student's t-test or Wilcoxon signed-rank test were used to compare outcomes before and after the treatment. After that, to predict changes in pelvic floor disorders, multiple linear regression models were performed. Each subsection and the total score of the PFDI-20 were used as dependent variables, while UL and hours/day spent in MPA were used as predictors, measured at the same time point as the questionnaire results. In cases where the overall model was not significant, additional linear regressions using each predictor separately were performed to explore their individual contributions to pelvic floor disorder scores. In addition, a delta (Δ) value was calculated to assess the difference between the two time points by subtracting each post-treatment variable from its corresponding pre-treatment variable. Multiple linear regression analyses were then performed for each Δ PFDI-20 subsection and total score as dependent variables, and Δ UL and Δ MPA as predictors. In addition, before performing the regression models, we checked whether the assumption of linearity, homoscedasticity, and normality of residuals were adequately met. Effect sizes were calculated using Cohen's d and Rosenthal's r for normally and non-normally distributed data, respectively. A p-value of less than 0.05 was considered statistically significant for all the analyses.

4.3 Results

Participants' attendance on the multimodal intervention was high, with the participants completing the full 5-week program with $97 \pm 7\%$ of presence across the 14 supervised classes. On average participants were slightly overweight (Table 4) and performed more than 150 min/week of daily PA at moderate-to-vigorous physical activity (MVPA).

Table 4. Study participant's characteristics at baseline. Summary statistics are presented as mean and $\pm$ standard deviation (SD).

Variable	Mean $\pm$ SD
Age (years)	57.40 $\pm$ 7.35
Height (cm)	160.10 $\pm$ 6.52
Weight (kg)	66.05 $\pm$ 11.06
BMI (kg/m ²)	25.73 $\pm$ 3.81

cm: centimetres; kg: kilograms; BMI: Body Mass Index; kg/m²: kilograms per square meter

The differences between pre and post intervention showed a significant reduction in UL after the treatment ($z = 3.92$, $p < 0.001$, $r = 0.88$) as well in PFDI-20 total score ($t = 2.71$, $p = 0.007$, $d = 0.56$), and in the two subsections of the questionnaire, POPDI-6 ($t = 2.15$, $p = 0.022$, $d = 0.46$) and UDI-6 ($z = 2.63$, $p = 0.004$, $r = 0.59$), respectively. The third subsection score (CRADI-8) showed a reduction, although it was not statistically significant. The average daily accelerometer wear time was > 15 hours in both the pre- and post-intervention assessments. A paired t-test showed no significant differences in wear time between the two periods. Physical activity, measured as hours/day spent at different intensities did not differ between pre and post intervention. Light-intensity physical activity (LIPA) ($t = -0.80$, $p = 0.430$, $d = -0.18$), MPA ($t = -0.93$, $p = 0.430$, $d = -0.18$), and steps per minute (SPM) ($t = 0.27$, $p = 0.785$, $d = 0.062$), all of them showed no significant changes. All results are summarised in Table 5.

Table 5. Differences between pre and post intervention in UL, physical activity levels, and PFDI-20 scores.

Variable	Pre	Post	Statistic	p
UL (ml)	4.80 (2.22–7.12)	2 (0.87–4.07)	$z = 3.92$	$< 0.001^*$
PFDI-20 (AU)	78.89 ± 48.90	54.44 ± 47.12	$t(19) = 2.71$	0.007^*
POPDI-6 (AU)	24.37 ± 19.03	15.83 ± 18.11	$t(19) = 2.15$	0.022^*
UDI-6 (AU)	35.41 (16.67–47.91)	18.75(3.12–37.50)	$z = 2.63$	0.004^*
CRADI-8 (AU)	18.77 ± 16.88	14.63 ± 15.13	$t(19) = 1.54$	0.069
LIPA (h/d)	3.78 ± 0.81	3.86 ± 0.89	$t(19) = -0.80$	0.430
MPA (h/d)	2.12 ± 1.23	2.22 ± 1.18	$t(19) = -0.93$	0.181
SPM (n)	15.61 ± 3.13	15.50 ± 2.69	$t(19) = 0.27$	0.785

Pre and Post results are presented as mean $\pm$ standard deviation, or median and Interquartile range (IQR) for non-normal distributed data, and statistics as t -values with degrees of freedom (*Student's* paired t -test) or z -values (*Wilcoxon* signed-rank test) with corresponding p -values. ml: millilitres; UL: Urinary loss; PFDI-20: Pelvic Floor Distress Inventory; AU: Arbitrary Unit; POPDI-6: Pelvic Organ Prolapse Distress Inventory; UDI-6: Urinary Distress Inventory; CRADI-8: Colorectal-Anal Distress Inventory; LIPA: light physical activity; MPA: moderate physical activity; h/d: hours a day; SPM: Steps per minute; *: significance

To contextualise the magnitude of change in symptom perception, the mean reduction in PFDI-20 scores was compared with published Minimal Clinically Important Difference (MCID) values. Previous studies reported a minimal important change of -13.5 points for conservative interventions 60 and -24 points for surgical populations 61. In our sample, the reduction (-26.7 points) exceeded both reference thresholds. Regarding the pre-intervention data, the multiple regression model with PFDI-20 as dependent variable showed a significant result ($F(2,17) = 4.956$, $p = 0.020$; $R^2 = 0.368$), with only MPA as a significant predictor ($B = -21.32$, $p = 0.013$). The model using POPDI-6 as dependent variable was also significant ($F(2,17) = 3.833$, $p = 0.049$; $R^2 = 0.311$), with MPA also as significant predictor ($B = -7.244$, $p = 0.033$). On the contrary, although the regression model with UDI-6 as dependent variable was significant ($F(2,17) = 4.256$, $p = 0.032$; $R^2 = 0.334$), the significant predictor was in this case UL ($B = 1.292$, $p = 0.029$). The model using the subsection CRADI-8 as the dependent variable was not significant.

The analyses performed with post-intervention data showed a significant result when PFDI-20 was used as the dependent variable ($F(2,17) = 5.578$, $p = 0.014$; $R^2 = 0.396$), with both predictors significant: UL ($B = 5.505$, $p = 0.008$), and MPA ($B = -16.269$, $p = 0.050$). The model using POPDI-6 was also significant ($F(2,17) = 7.030$, $p = 0.006$; $R^2 = 0.453$), with only UL as a significant predictor ($B = 2.418$, $p = 0.002$). The model using CRADI-8 as dependent variable was significant ($F(2,17) = 5.179$, $p = 0.018$; $R^2 = 0.379$), with both predictors significant: UL ($B = 1.386$, $p = 0.032$), and MPA ($B = -6.838$, $p = 0.015$). No significant result was found for the model using UDI-6. Table 6 shows all the multiple linear regression models performed.

Table 6. Coefficients from multiple linear regression analyses performed on pelvic floor perceived disorders before (pre) and after (post) intervention.

Model	Variable	B	SE	β	p
Pre PFDI-20	Intercept	109.057	19.785		<0.001
	UL (ml)	1.982	1.096	0.351	0.088
	MPA (h/d)	-21.329	7.702	-0.537	0.013*
Pre POPDI-6	Intercept	33.703	8.044		< 0.001
	UL (ml)	0.793	0.446	0.361	0.093
	MPA (h/d)	-7.244	3.131	-0.469	0.033*
Pre CRADI-8	Intercept	33.731	7.466		< 0.001
	UL (ml)	-0.102	0.414	-0.053	0.807
	MPA (h/d)	-6.664	2.906	-0.486	0.035*
Pre UDI-6	Intercept	41.625	9.785		< 0.001
	UL (ml)	1.292	0.542	0.475	0.029*
	MPA (h/d)	-7.420	3.809	-0.388	0.068
Post PFDI-20	Intercept	69.105	18.888		0.002
	UL (ml)	5.505	1.821	0.587	0.008*
	MPA (h/d)	-16.269	7.702	-0.410	0.050*
Post POPDI-6	Intercept	18.894	6.930		0.014*

	UL (ml)	2.418	0.668	0.669	0.002*
	MPA (h/d)	−5.175	2.826	−0.339	0.085
Post CRADI-8	Intercept	25.021	6.167		< 0.001
	UL (ml)	1.386	0.595	0.459	0.032*
	MPA (h/d)	−6.838	2.515	−0.536	0.015*
Post UDI-6	Intercept	27.095	10.005		0.016
	UL (ml)	1.607	0.951	0.395	0.111
	MPA (h/d)	−4.499	4.012	−0.262	0.279

B: unstandardized coefficient; SE: standard error; β : standardized coefficient; UL: Urinary loss; PFDI-20: Pelvic Floor Disorders Inventory; POPDI-6: Pelvic Organ Prolapse Distress Inventory; CRADI-8: Colorectal-Anal Distress Inventory; UDI-6: Urinary Distress Inventory; ml: millilitres; MPA: Moderate physical activity; h/d: hours a day; *: significance.

4.3.1 Delta (Δ) variables

To capture the individual variation in response to the intervention, the differences (Δ) between pre and post intervention values were calculated (Table 7).

Table 7. Descriptive statistics of Δ values representing the changes between pre and post intervention. Results are presented as mean and $\pm$ standard deviation.

Variable	Mean $\pm$ SD
Δ UL (ml)	−4.16 $\pm$ 6
Δ MPA (h/d)	0.10 $\pm$ 0.49
Δ PFDI-20	−26.76 $\pm$ 44.03
Δ POPDI-6	−8.54 $\pm$ 17.75
Δ UDI-6	−14.08 $\pm$ 24.12
Δ CRADI-8	−4.14 $\pm$ 11.95

ml: millilitres; UL: Urinary loss; MPA: moderate physical activity; h/d: hours a day; PFDI-20: Pelvic Floor Distress Inventory; POPDI-6: Pelvic Organ Prolapse Distress Inventory; UDI-6: Urinary Distress Inventory; CRADI-8: Colorectal-Anal Distress Inventory.

The multiple linear regression performed using Δ UL and Δ MPA as predictors of Δ PFDI-20 showed significance ($F(2,17) = 6.649$, $p = 0.007$; $R^2 = 0.439$). Δ UL was a significant predictor ($B = 3.253$, $p = 0.026$) as well as Δ MPA ($B = -41.430$, $p = 0.021$). The model using Δ POPDI-6 did not show significance, even though further explorative analyses were performed. Regarding the multiple regression using Δ CRADI-8, the model was significant ($F(2,17) = 4.599$, $p = 0.025$; $R^2 = 0.351$), with only Δ MPA as a significant predictor ($B = -14.483$, $p = 0.008$). Finally, the model using Δ UDI-6 was also significant ($F(2,17) = 6.801$, $p = 0.007$; $R^2 = 0.444$), with only Δ UL as a significant predictor ($B = 2.319$, $p = 0.005$). Table 8 shows all the multiple linear regression models performed.

Table 8. Coefficients from multiple linear regression analyses performed on pelvic floor perceived disorders using delta (Δ)

Model	Variable	B	SE	β	p
Δ PFDI-20	Intercept	-9.001	9.651		0.364
	Δ UL (ml)	3.253	1.336	0.444	0.026*
	Δ MPA (h/d)	-41.430	16.345	-0.461	0.021*
Δ POPDI-6	Intercept	-3.005	4.482		0.512
	Δ UL (ml)	1.026	0.620	0.347	0.117
	Δ MPA (h/d)	-12.434	7.596	-0.343	0.120
Δ CRADI-8	Intercept	-3.047	2.818		0.295
	Δ UL (ml)	-0.093	0.390	-0.047	0.815
	Δ MPA (h/d)	-14.483	4.776	-0.594	0.008*
Δ UDI-6	Intercept	-2.952	5.262		0.582
	Δ UL (ml)	2.319	0.728	0.577	0.005*
	Δ MPA (h/d)	-14.516	8.917	-0.295	0.122

B: unstandardized coefficient; SE: standard error; β : standardized coefficient; UL: Urinary loss; PFDI-20: Pelvic Floor Disorders Inventory; POPDI-6: Pelvic Organ Prolapse Distress Inventory; CRADI-8: Colorectal-Anal Distress Inventory; UDI-6: Urinary Distress Inventory; ml: millilitres; MPA: Moderate physical activity; h/d: hours a day; *: significance.

4.4 Discussion

The present study investigated the effects of a five-week multimodal intervention on UL, MPA, and the perception of pelvic floor disorders in adult women with UI. The main results showed a significant reduction in UL and perceived pelvic floor disorders, while no significant change was observed in average MPA levels although a little improvement in the time spent at that intensity. This represents a good starting point for future protocols aimed at increasing MPA. Indeed, recent evidence shows that moderate physical activity can improve several health indicators even in the presence of sedentary behavior^{70,71}. Regression models highlighted an interesting change in the relationship between objective variables and subjective perceptions, with relevant implications for both clinical and physiological interpretation. Before the intervention, scores related to pelvic floor disorders (PFDI-20) were significantly and inversely associated with MPA. Although the objectively measured amount of UL did not emerge as a significant predictor, its association with the total PFDI-20 score showed a positive trend toward significance. This finding may suggest that, initially, participants did not associate pelvic floor disorders to their daily routine. In other words, these participants were physically active because they did not perceive UL as a limitation, probably also because objectively measured UL was minimal. On the other hand, the significant negative association that emerged between MPA and the PFDI-20 could indicate that MPA may contribute to a more favourable perception of pelvic floor disorders. Among the subsections, POPDI-6 was significantly predicted by MPA, as well as CRADI-8, indicating that higher levels of MPA were associated with fewer prolapse and colorectal disorders perception. These results may suggest that more active participants in daily life reported fewer disturbances, confirming the previous findings⁵². In contrast, UDI-6, focused on urinary disorders, was predicted by the actual amount of UL, confirming that, even before treatment, urinary perceptions aligned more directly with physiological measures as demonstrated by previous evidence⁷². However, it is important to note that the predictive value of pad-test-based urinary loss can be influenced by methodological variability and individual behavioural factors, as highlighted in a recent systematic review⁷³. On the other hand, after the intervention, the perception of pelvic floor disorders was significantly associated with UL, with a reduction in the predictive role of MPA.

We hypothesize that the change in the association between subjective and objective measurements could be explained by an evolution in the body awareness of the participants, potentially favoured by breathing exercises, posture correction, and IAP management. Indeed, the intervention was designed as also an educational and proprioceptive path, intended to make participants more able to control their pelvic floor muscles⁷⁴. This approach appears to support the hypothesis that greater body awareness, fostered by the multimodal intervention, may contribute to an improvement in symptom perception even in the absence of substantial changes in physical activity levels. Post intervention regression models, using the subsections, confirmed this shift in perception. Indeed, both POPDI-6 and CRADI-8 became significantly associated with UL more than MPA. On the other hand, the subsection UDI-6 related specifically to perceived urinary disorders, despite a significant reduction in mean score, was no longer significantly predicted by either variable. This result may support the previous hypothesis concerning increased body awareness, which could reduce hyperfocus on symptoms and lead to a less distressed interpretation of urinary sensations⁷⁵. Furthermore, the association between urinary loss, MPA and perception of pelvic floor disorders was confirmed in the models based on pre-post variations (Δ). Specifically, Δ UL and Δ MPA levels were significant predictors of Δ PFDI-20. Regarding the other subsections, Δ UL was a significant predictor of Δ UDI-6, whereas Δ MPA levels influenced Δ CRADI-8. Regarding the subsection Δ POPDI-6, the model did not reach significance, probably because of higher variability between participants. These results may suggest that, although there were no significant changes in MPA levels across the sample, individual improvements in physical activity may still have clinically relevant effects on pelvic floor disorders in general, especially in domains linked to colorectal-anal disturbances. Previous research on postmenopausal women has shown that high adherence to moderate-intensity physical activity is associated with metabolic health benefits, regardless of sedentary time, and that different patterns of physical activity may lead to similar positive outcomes⁷⁶. Although there is evidence that women often reduce their participation in physical exercise, especially when it is moderate to vigorous, due to pelvic floor disorders⁷⁷, these results could indicate that improving overall fitness and body awareness may motivate women with UI to participate in physical activity and exercise. In contrast, limited body

awareness and, consequently, difficulty in recognizing actual pelvic floor dysfunctions may lead to poor adherence to physical activity⁷⁵. It is important to acknowledge that both urinary loss and physical activity measures may be influenced by methodological limitations inherent to the instruments used. Long-term home pad tests (24–48 h), while widely employed and ecologically valid, are sensitive to natural day-to-day fluctuations in hydration, daily activities, stress, or environmental conditions, which may partially contribute to the variability observed in urinary loss measurement^{64,78}. A further methodological consideration concern wrist-worn accelerometry. Although wrist placement improves wear compliance, validated cut-points and algorithms for classifying physical activity intensity in adults are still limited. Current approaches rely on site- and sample-specific calibration procedures, and only a small number of wrist-specific algorithms have been developed and validated for free-living adult populations. This lack of standardisation may reduce the precision and comparability of wrist-based activity estimates in the present study^{36,79,80}.

4.5 Limitations

Although the results were promising, the present study has some limitations. First, the small sample size leads us to interpret the findings with caution. Indeed, a larger sample will be necessary to confirm the results. Secondly, the experimental design did not provide a control group to verify the efficacy and specificity of the intervention, or the spontaneous disturbances fluctuations related to seasonality or other external factors. In addition, several behavioural and physiological factors that may influence both UL and symptom perception, such as hydration patterns, daily habits, stress levels, climate conditions, medication use, and menstrual cycle phase, were not controlled. These elements are inherent challenges of free-living measurements, particularly in long-term pad tests, but nonetheless may have contributed to inter-individual variability. Moreover, although IAP management was a core principle of the intervention, IAP was not directly assessed, therefore mechanistic effects related to pressure modulation should be interpreted with caution. Lastly, the intervention was of short duration. Although effective, the period was relatively short compared to other intervention protocols, and furthermore, the absence

of a follow-up evaluation, did not allow assessment of the long-term maintenance of the observed effects. Future studies should consider longer interventions, include follow-up assessments, and adopt designs incorporating control groups to better clarify causal relationships and the stability of the observed improvements.

4.6 Conclusions

The results show that after the intervention, the pelvic floor disorders perception was more associated with UL than with MPA levels. This change may suggest an evolution in body awareness of the participants, who appears to be more capable to linking disorders to real physiological signals. The approach used, which integrates breathing, posture and pressure control, is useful not only for muscle strengthening, but also for perceptual education. Moreover, this multimodal intervention appears feasible, clinically translatable, and non-invasive for women. These results partially appear to confirm the first hypothesis, showing that the reduction of UL could be an important predictor of the perceived improvements, whereas the role of physical activity appears more selective and dependent on individual variability. From a clinical perspective, the protocol may represent a promising complementary strategy to traditional PFMT, offering an accessible option for women with mild UI who may benefit from improved proprioception and pressure management. Future studies should confirm these preliminary results in larger and controlled samples, explore the relative contribution of each component of the multimodal approach, and include longer follow-up periods to assess the stability of the observed improvements. Integrating objective measures with validated body-awareness scales and refining activity monitoring methods may further enhance the understanding and applicability of this intervention in clinical and preventive settings.

**5. STUDY 3: Physical Activity, Sleep Patterns, and
Their Association in Youth With Type 1 Diabetes
Before and During a Structured Summer Camp**

5.1 Introduction

Type 1 diabetes (T1D) is a chronic autoimmune disease in which the immune system destroys pancreatic β -cells, leading to loss of endogenous insulin production, responsible for transporting glucose from the bloodstream into cells. Its absence causes a condition named hyperglycemia, which in turn can lead to multiple complications⁸¹. T1D usually begins in childhood or adolescence, and its management typically includes exogenous insulin injections, continuous glucose monitoring, appropriate nutrition, and education, involving both patients and families⁸². Physical activity also plays a key role. The American Diabetes Association recommends regular exercise for improving cardiovascular fitness, bone-health, insulin sensitivity, and enhancing psychological well-being in patients with T1D⁸³. Physical activity may also reduce insulin requirements because muscle contractions promote insulin-independent glucose uptake⁸⁴. The World Health Organization (WHO) recommends that children and adolescents accumulate at least 60 minutes/day of moderate to vigorous physical activity (MVPA) and engage in muscle-strengthening activities three times per week. These recommendations apply to youth with T1D as well⁸⁵. According to the International Society for Pediatric and Adolescent Diabetes (ISPAD), a minority of young patients with T1D manage to meet these activity targets, as patients tend to be less active and more sedentary compared to their peers without diabetes⁸⁶. A study involving 201 children with T1D revealed significant barriers hindering physical activity among this population. The highest barrier scores included loss of diabetes control, fear of hypoglycemia, and concerns related to external temperature⁸⁷. The literature indicates that insufficient physical activity among children and adolescents with T1D is often accompanied by lower physical fitness, particularly strength, coordination and speed^{88,89}. Moreover, studies in youth with T1D consistently report increased arterial stiffness compared with healthy peers⁹⁰, indicating early vascular alterations. While pediatric data on trunk flexibility in T1D are limited, evidence from adults shows that lower trunk flexibility is associated with a greater age-related increase in aortic stiffness⁹¹. Sleep is another relevant health and lifestyle behavior. The American Academy of Sleep Medicine suggests 9–12 hours of sleep per night for children and 8–10 hours for adolescents, with night awakenings lasting a maximum of 20 minutes⁹². A recent systematic

review indicates that youth with T1D often experience shorter sleep, greater fragmentation, and more sleep disturbances, which may adversely affect glycemic management ⁹³. Greater physical activity levels are generally associated with better sleep quality. In particular, moderate physical activity (MPA) may be more effective than light activity (LIPA) or vigorous activity (VPA) in improving sleep. Conversely, prolonged sedentary behavior, especially long period of screen time, is linked to poorer sleep ⁹⁴. Beyond total volume of activity, the context may matter. Conducting physical activity in natural environments has been associated with sleep and mood benefits, potentially influenced by environmental characteristics such as air quality, temperature, and visual features like colours ⁹⁵. Furthermore, structured settings can also help in improving physical activity. In youth with chronic conditions, participation in organized physical exercise programs tends to reduce barriers and increase participation ⁹⁶. Summer camps with structured activities have been shown to promote higher levels of MVPA compared with less organized camps ^{97,98}. However, to our knowledge, no studies have using objective measures to compare physical activity, sedentary behavior, and sleep, before versus during participation in a summer camp for youth with T1D. Moreover, there is a lack of studies investigating how engaging in physical activity in natural and structured settings affects sleep quality specifically in youth with T1D. Based on this background, we hypothesized that participation in a 10-day summer camp would increase physical activity levels, reduce sedentary time, and improve sleep in children and adolescents with T1D. Accordingly, our aims were: (i) to describe participants' baseline status before camp, assessing physical fitness, physical activity, sedentary behavior, and sleep using both objective and subjective measures, and (ii) to compare objective physical activity, sedentary behavior, and sleep patterns before and during the camp.

5.2 Materials and Methods

5.2.1 Participants

Participants included children and adolescents with T1D, regularly followed by the medical staff of the Pediatric Endocrinology Unit, 3rd Department of Paediatrics, situated at Hippokration General Hospital (Thessaloniki, Greece). In the absence of directly comparable studies, a priori

power analysis was conducted in G*Power (version 3.1.9.4) comparing pre camp–during camp for a moderate-to-large effect size ($d = 0.70$), consistent with expected changes in physical activity/sedentary time and sleep during structured residential programs. Using a two-tailed paired t-test ($\alpha = 0.05$; power 0.85), results indicated that total sample size should be $n = 21$ participants. A total of twenty-three children and adolescents (mean age: 13.33 ± 2.13 years; 10 boys and 13 girls) were enrolled for the study. Inclusion criteria were: (i) a confirmed diagnosis of T1D; (ii) age 6–17; (iii) absence of diabetes-related comorbidities/complications; (iv) no musculoskeletal injury before or during the monitoring period that could have compromised participation in the study activities; (v) medical eligibility to safely perform the fitness tests, with no contraindications. After obtaining informed consent from the families, participants underwent a baseline assessment at the clinic, conducted two weeks prior to their participation at a Diabetes Summer Camp. Participants’ characteristics are presented in Table 9. The protocol was approved by the Scientific committee of the Ippokratio General Hospital (33475/19-7-2024).

Table 9. Study participants’ characteristics at baseline.

Variable	Mean $\pm$ SD
Age (years)	13.33 ± 2.13
BMI (z-score)	0.72 ± 1.47
HbA1c (%)	6.96 ± 0.65

Summary statistics are presented as mean and $\pm$ standard deviation (SD). BMI: Body Mass Index; z-score: number of SDs from the mean; HbA1C: Glycated Hemoglobin; %: Percentage.

5.2.2 Study design

This study employed a longitudinal observational design with two data collection phases. Data were collected under two different conditions: school holidays, during participants’ usual routines, and subsequently during a structured summer camp.

5.2.3 Procedure

Phase 1: Baseline assessment at the end of the school year

During the last two weeks of July, participants and their families visited the Paediatric Unit of the Ippokratio General Hospital in Thessaloniki, where routine medical evaluations were performed. After that evaluation, a baseline assessment was conducted. Each participant completed three physical fitness tests and, additionally, each child received a wearable device and its charger to objectively measure daily physical activity and sleep patterns over a 7–8 day period continuously day and night. Families were instructed on device use, account setup, and synchronization procedures. At the end of the 7–8 days of recording, participants received two standardized questionnaires assessing subjective physical and sedentary activities and completing them before the participation at the camp.

Phase 2: Monitoring during the summer camp

From the last two days of July participants attended a 10-day Diabetes Summer Camp organized by the YMCA (Young Men's Christian Association) in Chalkidiki, Greece. The participating children and adolescents were still wearing the electronic devices that were provided to them during their clinic visit in the previous week and participated in three physical and recreational activities each day, two in the morning and one in the afternoon. Figure 3 details the procedure timeline.

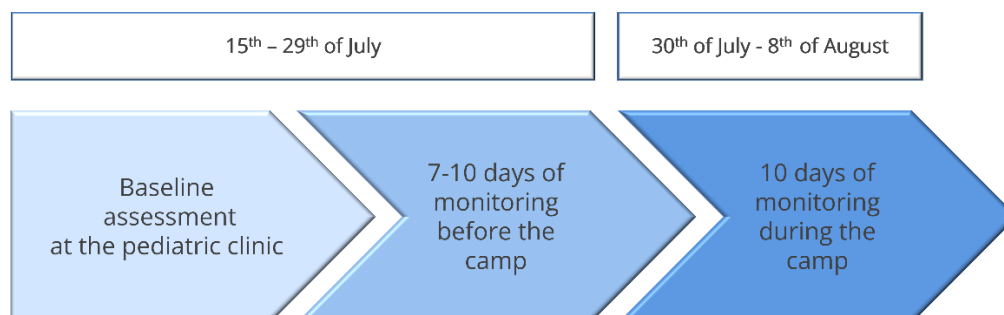


Figure 3. Procedure timeline from the first assessment at the paediatric clinic to the summer camp.

5.2.4 Camp structure and daily schedule

The summer camp was held in a large natural environment located at high altitude, with direct access to the sea, situated at the Chalkidiki peninsula, in Greece. The camp's structure encouraged continuous movement throughout the day, as participants had to walk between the different areas where activities, meals, and sleep accommodations were located. The daily program was organized into three main physical activity sessions, two in the morning and one in the afternoon, which included swimming, basketball, volleyball, climbing, and other recreational and educational games. In addition, campers participated in collective routines and leisure moments that further contributed to overall daily movement. A typical daily schedule of the camp is presented in Figure 4, showing the structured alternation of physical activities, meals, rest, and recreational periods.

CAMP DAILY TIMETABLE	
TIME	ACTIVITY SCHEDULE
7.45	AWAKENING
8.00	SETTING THE TABLES (ONLY 2 CAMPERS, NOT THE WHOLE TENT)
8.10	RAISING THE FLAG
8.20	BREAKFAST
8.45	BED ETC SET-UP
9.30	INSPECTION
10.00	FIRST ACTIVITY
11.15	SECOND ACTIVITY
12.30	END OF ACTIVITIES
13.00	SETTING THE TABLES (ONLY 2 CAMPERS, NOT THE WHOLE TENT)
13.10	LUNCH
14.00	CANTEEN - FREE TIME
15.00	MID DAY REST
16.45	AFTERNOON SNACK
17.15	AFTERNOON ACTIVITY
18.30	END OF ACTIVITIES
19.00	SETTING THE TABLES (ONLY 2 CAMPERS, NOT THE WHOLE TENT)
19.10	FLAG LOWERING
19.20	DINNER
20.00	CANTEEN - FREE TIME
21.00	ENTERTAINMENT (THEATRICAL OR GAMES WITH PA OR BEACH NIGHT SLEEPING
22.30	BED TIME

Figure 4. Camp daily timetable showing the structured organization of activities, meals, and rest periods throughout the day.

5.2.5 Physical Fitness Tests

Participants underwent a brief set of physical fitness assessment tests to evaluate motor abilities, including strength, coordination, and flexibility. The Handgrip Strength Test was used to evaluate upper body muscular strength, using a hand dynamometer (Gima S.p.A.). Participants were seated

on a chair with their shoulders adducted and in a neutral position, elbows flexed at 90°, forearms and wrists in a neutral position. They were instructed to hold the hand dynamometer and squeeze it with maximal effort for five seconds, alternating between hands. The highest attained value, corresponding to peak force, was recorded in kilograms ⁹⁹. The Plate Tapping Test, designed to assess hand-eye coordination and speed, involved two sets of 50 alternating touches on two target circles placed on either side of a central rectangle. The dominant hand performed the task, while the non-dominant hand remains stationary over the rectangle. Two attempts were performed and the best result, corresponding to the shorter time spent, was recorded ¹⁰⁰. Finally, Trunk Lift Test was used to measure trunk extensor strength and flexibility. The participant lay prone on a mat with hands behind the neck and slowly lifted the upper body off the examination table, keeping the head aligned with the spine. The height from the floor to the chin was measured, and the best of two attempts was recorded. The test required a second operator to stabilize the lower body. Handgrip Strength and Plate tapping tests results were standardized by matching each participant's best attempt to age and sex specific reference percentiles¹⁰¹. Regarding the Trunk lift test, in accordance with FitnessGram® performance standards ¹⁰², results were classified into three categories: below the Healthy Fitness Zone (HFZ), within the HFZ, and above the HFZ. The HFZ is defined as 6–12 inches for ages 6–9 and 9–12 inches for ages 10–17+.

5.2.6 Questionnaires

To collect subjective data on physical activity and sedentary behaviors, two validated questionnaires were administered to participants, each referring to the previous seven days spent wearing the electronic devices. The first tool was the Greek version of the Adolescent Sedentary Activity Questionnaire (ASAQ) ^{103,104}, designed to assess time spent in a wide range of sedentary activities across five domains: recreational screentime, educational, cultural, social, and transportation. Participants reported the time spent on each behavior during both a typical weekday and weekend day. The questionnaire is divided into two sections, one for weekdays and one for weekends, and the total sedentary time is calculated by summing the minutes reported across all items for both time periods. The second instrument was the Greek version of the

Physical Activity Questionnaire for Children (PAQ-C) ^{105,106}, a self-administered, 7-day recall questionnaire developed to evaluate general levels of physical activity in children, aged between 8 to 14 years of age. The questionnaire was adapted by removing items related to time spent at school, as data collection took place during the summer holiday period. The final score is derived from nine items, each rated on a 5-point scale, where higher scores indicate greater physical activity levels. Specifically, a score of 1 corresponds to a very low activity level, 2 to low, 3 to moderate, 4 to high, and 5 to very high physical activity levels.

5.2.7 Wearable Device

To objectively assess daily physical activity, sedentary behavior, and sleep parameters, participants were equipped with two types of Fitbit devices (Fitbit Inc., San Francisco, CA, USA): the Fitbit Ace 3 and the Fitbit Inspire HR, assigned according to the participant's age ^{107,108}. These devices record step counts at one-minute intervals, heart rate every five seconds, and the number of minutes spent each day at different intensities of physical activity (light, moderate, and vigorous). Additionally, sleep related variables were collected, including time asleep, duration of awakenings, and sleep efficiency ¹⁰⁹. Participants were instructed to wear the device continuously, both day and night, on their non-dominant wrist to minimize overestimation of movement. Families received detailed guidance on how to install the Fitbit mobile application, create individual accounts, and synchronize the devices to ensure consistent and complete data collection. Informed consent also included authorization to access and retrieve the data recorded by the devices. After the investigation period, families were instructed to access their child's Fitbit account and download the data recorded throughout the entire period. They then provided the downloaded data to the research team. The collected data included the daily time spent in light, moderate, vigorous, and sedentary activity, expressed in minutes per day. Regarding sleep, the downloaded data reported the number of daily minutes spent asleep and awake, as well as the daily percentage of sleep efficiency, which indicates sleep quality. For each investigation phase, the minutes recorded for each variable were summed and divided by the number of days in that phase to obtain the average daily values.

5.2.8 Anthropometric measurements

Body weight and height of participants were measured during early morning hours, with the subjects barefoot, wearing the minimum amount of clothes possible. One experienced dietitian (E.G.P.) performed all body measurements during morning hours. A standardized procedure was followed for weighing and measuring body height, in order to minimize measurement error and frequent calibration of the scale was performed with portable fixed weights, to ensure measurement accuracy. A mechanical scale (Seca 700, Seca, Hamburg, Germany) and a wall-mounted stadiometer (Harpender, Holtain, Crymych, UK) were employed, both situated at the Pediatric Endocrinology Unit. The body mass index (BMI) of each participant was calculated as the ratio of body weight (kg), divided by stature (m²). The World Health Organization's (WHO) Anthro software v.3.2 (WHO, Geneva, Switzerland) was used for the calculation of BMI z-score (BMIz) in each participant. The WHO Anthro software is based on the WHO child growth standards and growth curves ^{110,111}.

5.2.9 Statistical analysis

Statistical analyses were conducted using JASP software (version 0.19.1, University of Amsterdam, Netherlands). The Shapiro-Wilk test was used to assess the normality of data distribution across both phases of the study. Descriptive statistics were performed to explore the basal conditions and the conditions during the camp of the participants, examining the variables related to fitness, physical activity, sedentary, and sleep. To evaluate changes between the periods, paired-sample t-tests were performed on physical activity and sleep variables: Student's paired t-test when the distribution of pre-during differences met normality, and the Wilcoxon signed-rank test otherwise. Effect sizes were reported as Cohen's d for t-tests and the matched rank-biserial correlation (r_b) for Wilcoxon tests. To assess the influence of movement on sleep quality, linear regression models were performed for both periods, before the camp and during the camp. Assumptions of linear regression were examined for both models. Multicollinearity was assessed through Variance Inflation Factor (VIF) and tolerance values, with all VIFs equal to 1.00, indicating absence of collinearity. Residual plots and standardized residuals confirmed

homoscedasticity and normal distribution of errors, with no influential outliers detected. A p-value < 0.05 was considered significant.

5.3 Results

5.3.1 Basal assessment – Fitness tests

Upper limb strength was below average, indeed the results of the Handgrip test showed that most participants were below the age and sex specific 10th percentile (Figure 2). In contrast, the results related to the Plate tapping test showed that the upper limb speed and coordination was above average, with most participants scoring above the 50th percentile (Figure 3). For the Trunk lift test, the sample was, on average, within the Healthy Fitness Zone according to the FitnessGram®. Specifically, twelve participants fell within the Healthy Fitness Zone normal range, three below it, and eight above the upper threshold (Figure 5).

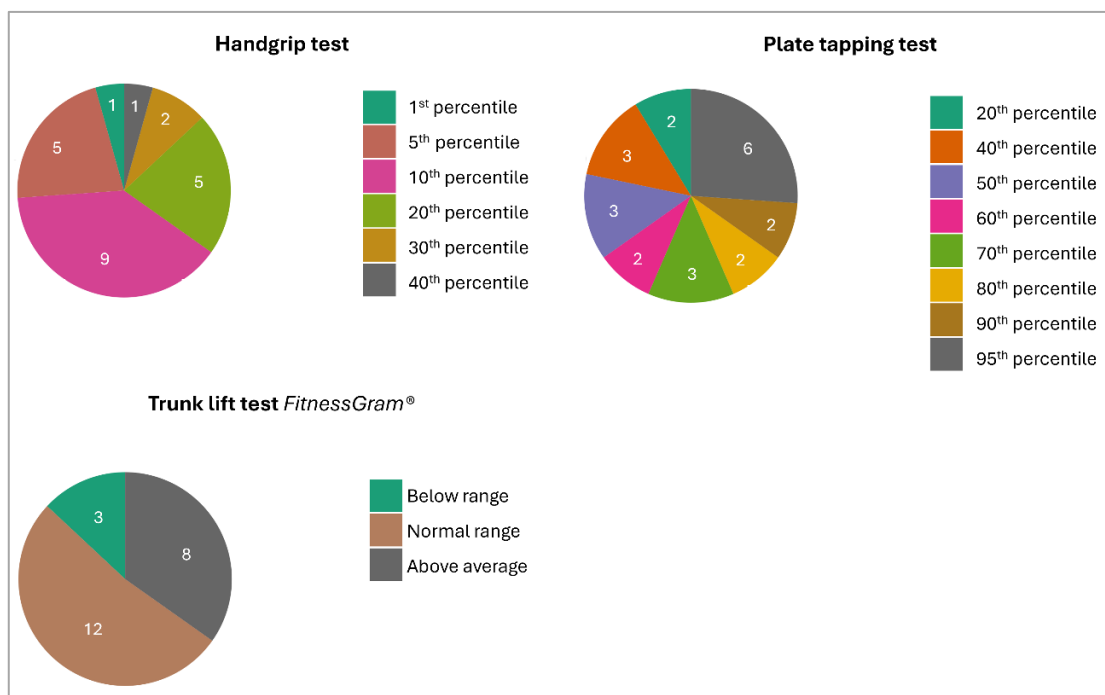


Figure 5. Distribution of participants across normative percentiles in the Handgrip test and Plate tapping test, and distribution of participants across Healthy Fitness Zone according to the FitnessGram® in the trunk lift test.

5.3.2 Basal assessment – Self-reported Physical Activity and Sedentary Behavior

The PAQ-c indicated a low activity level. Conversely, the ASAQ corroborated these findings by showing prolonged sedentary time on both weekdays and weekends. Further details for the ASAQ subsections are reported in Table 10.

Table 10. Results related to Physical Activity Questionnaire for Older Children and Adolescents Sedentary Activities Questionnaire.

Variable	Mean $\pm$ SD
PAQ-c (PAL)	1.68 $\pm$ 0.47
ASAQ WD Screen time (min/day)	264.13 $\pm$ 175.76
ASAQ WE Screen time (min/day)	255 $\pm$ 175.82
ASAQ WD Education (min/day)	115.21 $\pm$ 98.35
ASAQ WE Education (min/day)	49.23 $\pm$ 74.12
ASAQ WD Travel (min/day)	32.60 $\pm$ 50.71
ASAQ WE Travel (min/day)	28.47 $\pm$ 34.16
ASAQ WD Culture (min/day)	117.60 $\pm$ 119
ASAQ WE Culture (min/day)	106.95 $\pm$ 91.28
ASAQ WD Social (min/day)	91.30 $\pm$ 69.74
ASAQ WE Social (min/day)	81.19 $\pm$ 67.83
ASAQ WD Sedentary time (min/day)	620.87 $\pm$ 225.22
ASAQ WE Sedentary time (min/day)	521.04 $\pm$ 222.85

Statistics are presented as mean and $\pm$ standard deviation (SD). PAQ-c: Physical Activity Questionnaire for Older Children; PAL: Physical Activity Level; ASAQ: Adolescents Sedentary Activity Questionnaire; WD: Weekday; WE: Weekend; min/day: minutes/day.

5.3.3 Basal assessment – Device-based Physical Activity, Sedentary Behavior and Sleep

The participants accumulated an average of 8772.13 $\pm$ 2.823.75 steps/day and spent 258.34 $\pm$ 52.69 min/day in LIPA, 28.48 $\pm$ 16.40 min/day in MPA, and 24.66 $\pm$ 18.11 min/day in VPA. In

other hand, the time spent in sedentary was long with an average of 717 ± 80.61 min/day. Regarding sleep, they slept 408.89 ± 61.32 min/night with 46.10 ± 16.95 min/night of awake time (wake after sleep onset). Finally, sleep efficiency averaged $93.56 \pm 2.26\%$.

5.3.4 Pre Camp vs During Camp

Physical activity improved during the camp compared to the pre camp period. The number of steps increased significantly ($p < .001$, $d = -2.85$), as well as the time spent in different physical activity intensities, LIPA ($p < .001$, $r_{rb} = -1$), MPA ($p < .001$, $d = -1.07$), and VPA ($p = 0.008$, $r_{rb} = -0.56$). Conversely, the time spent in sedentary significantly decreased ($p < .001$, $d = 1.77$). Regarding sleep, the time spent asleep decreased significantly ($p < .001$, $d = 0.96$), as well as the duration of the awakenings ($p = 0.005$, $d = 0.65$). Table 11 shows the details.

Table 11. Mean differences (Δ), test statistics, and effect sizes for physical activity, sedentary behavior, and sleep variables between the pre-camp and during-camp periods.

Variable	Δ	Statistic	Effect size	p
Daily steps (n/day)	10129.75 ± 3552.31	$t = -13.67$	$d = -2.85$	$<0.001^*$
LIPA (min/day)	178.01 ± 59.16	$z = -4.19$	$r_{rb} = -1$	$<0.001^*$
MPA (min/day)	42.42 ± 39.49	$t = -5.16$	$d = -1.07$	$<0.001^*$
VPA (min/day)	14.71 ± 27.88	$z = -2.37$	$r_{rb} = 0.56$	0.008^*
Sedentary (min/day)	-211.46 ± 119.12	$t = 8.51$	$d = 1.77$	$<0.001^*$
Time Asleep (min/night)	-43.76 ± 45.13	$t = 4.64$	$d = 0.96$	$<0.001^*$
Time Awake (min/night)	-6.43 ± 9.58	$t = 3.15$	$d = 0.65$	0.005^*
Efficiency of sleep (%)	0.27 ± 1.83	$t = -0.824$	$d = -0.17$	0.419

Δ values are expressed as mean $\pm$ standard deviation (During Camp – Pre Camp). Effect sizes are reported as Cohen's d for paired t -tests and rank biserial correlation (r_{rb}) for Wilcoxon tests. Pre-camp and during-camp results are compared to evaluate changes in daily physical activity, sedentary behavior, and sleep. n: number; min: minutes; LIPA: Light Physical Activity; MPA: Moderate Physical Activity; VPA: Vigorous Physical Activity; *: significance.

5.3.5 Regression Analyses on Movement and Sleep Quality

A linear regression analysis examined the association between pre-camp sedentary time and the average duration of nocturnal awakenings. The model was significant ($F(1, 21) = 5.44$, $B = 0.095$, $p = 0.030$) explaining 20.6% of the variance ($R^2 = .206$; Adj. $R^2 = .168$). Sedentary minutes showed a positive association with awakening duration. A second linear regression analysis assessed the association between the change in daily steps (delta steps) and awakening duration during the camp. This model was significant as well ($F(1, 21) = 13.61$, $B = 0.002$, $p = 0.001$) accounting for 39.3% of the variance ($R^2 = .393$; Adj. $R^2 = .364$). Delta daily steps were positively associated with awakening duration.

5.4 Discussion

The baseline assessment revealed a specific physical activity and sedentary pattern in children and adolescents with T1D: the levels of physical activity were lower than the recommended levels, while the time spent in sedentary activities was very long. In particular, screen-time was longer than the recommendations of international guidelines. Indeed, from the data recorded by accelerometry and questionnaires, the participants did not reach the minimum amount of physical activity recommended by the WHO, corresponding to at least 60 minutes per day of MVPA and reduced sedentary time⁸⁵. These results are consistent with recent literature⁸⁶, which shows that young people with T1D tend to be less active and more sedentary compared to their healthy peers, also because of psychological barriers such as fear of hypoglycemia, losing glycemic control and external temperature⁸⁷. With regards to physical fitness, most of the participants showed handgrip strength values below the average compared to their healthy peers, in line with what has been reported in the literature, which describes significantly reduced muscle strength in youth with T1D, likely due to chronic metabolic alterations, reduced insulin availability, and decreased participation in resistance activities^{88,112}. The results herein regarding trunk flexibility are not directly comparable with the existing studies. In one study, for example, the side-bending test was used, highlighting lower flexibility values in youth with T1D compared to the peers without T1D¹¹². However, in the present study, the Trunk Lift test was employed¹⁰², which assesses a related but not identical domain. Despite this methodological difference, the discrepancy between the

results suggests that certain components of flexibility may be preserved in youth with T1D and deserve further investigation. In the present study, more than half of the participants achieved above average results in the Plate Tapping test, suggesting that upper-limb speed and coordination are relatively preserved in this population. This finding partially contrasts with what was reported by Lukács et al. (2012) ⁸⁸, who observed lower performance compared to healthy controls, probably because of differences in sample characteristics (e.g. age, disease duration), or different levels of habitual physical activity, and we could hypothesize that some neuromotor abilities may be less vulnerable to the effects of T1D. Regarding sleep, the baseline data confirmed the presence of suboptimal parameters, with a duration shorter than the international recommendations ¹¹³ and the presence of sleep fragmentation. The literature shows that young people with T1D tend to present shorter sleep duration and higher sleep fragmentation, elements that can negatively influence glycemic management and quality of life ⁹³. Furthermore, a bidirectional association has been suggested in youth, where sedentary behavior is linked to more fragmented sleep, and poor sleep quality predicts greater sedentary time ^{114,115}. The regression analysis offered additional insight into this relationship highlighting a positive association between the time spent in sedentary behavior and the duration of nocturnal awakenings. In particular, longer sedentary time was associated with more nocturnal awakenings, suggesting that lower daytime activity may contribute to less consolidated sleep, in line with previous evidence ^{115,116}. Participation in a structured summer camp led to significant changes in motor behavior and sleep patterns, consistent with studies showing structured camps can significantly increase MVPA in youth ⁹⁶. These results were consistent with those reported in other studies ⁹⁷, according to which structured environments such as camps represent effective contexts to overcome barriers and increase participation in physical activities in young people with chronic diseases. Regarding sleep, a significant qualitative improvement emerged, highlighted by the reduction in the duration of awakenings, despite a reduction in total sleep time. To complement these findings, we examined whether individual variation in physical activity was associated with changes in sleep continuity. Using the delta score for steps, which captures how much each participant increased or decreased their daily steps relative to baseline, we observed a positive association with awakening duration.

This means that participants who increased their daily steps more markedly compared with their own pre-camp levels tended to experience slightly longer nighttime awakenings. Although this result may appear inconsistent with the overall improvement in sleep quality observed during the camp, it likely reflects the specific context of the camp. The camp was located at altitude and extended across a large area, requiring participants to walk considerable distances between the sleeping quarters, the dining hall, the areas dedicated to glycemic monitoring, and the spaces used for daily activities. In addition, all participants took part in several scheduled physical activity sessions. Evidence suggests that very high volumes of daily movement or physically demanding conditions may contribute to physiological stress and fragmented sleep, particularly when activity levels substantially exceed an individual's habitual baseline ¹¹⁷. Consequently, even though physical activity is generally associated with better sleep quality, the substantial amount of movement required by the camp setting may have contributed, at an individual level, to more fragmented sleep and slightly longer nocturnal awakenings among those who increased their daily steps the most. The camp context may have further influenced sleep quality through environmental features. Natural environment could have a positive effect on sleep through environmental variables such as temperature, sounds, air quality, and visual characteristics ^{29,95}. The circadian system influences metabolic processes, glucose homeostasis, and hormonal secretion, and its disruption has been linked to insulin resistance and glycemic variability ¹¹⁸. From a physiological perspective, the observed results could be interpreted in the context of an interaction among physical activity, sleep, and the circadian metabolic system. Although we did not directly assess circadian phase markers, the qualitative improvement in sleep observed during the camp, despite the reduction in total sleep duration, may reflect a more favourable alignment of behavioral rhythms. Physical activity is known to act as a zeitgeber, a powerful external synchronizer of the biological clock, contributing to the regulation of circadian rhythms and the maintenance of metabolic homeostasis ¹¹⁹. In individuals with T1D, who show increased vulnerability of circadian regulation due to glycemic fluctuations and hormonal alterations, the regularity of daily behaviors, including structured physical activity, consistent meal timing, exposure to natural light, and sleep, may help stabilize homeostatic mechanisms and improve

insulin sensitivity¹¹⁸¹. Observational evidence shows that greater sleep variability is linked to worse and unstable glycemic management¹²⁰, although these interpretations should be considered with caution, as the present study did not directly measure circadian variables. Future research should include specific chronobiological assessments to confirm whether structured physical activity interventions can modulate circadian rhythm and metabolic outcomes in youth with T1D.

5.5 Limitations

This study had some limitations. First, the short observation period might not have been long enough to capture the long-term effects of physical activity and behavioral changes on sleep pattern. Second, the absence of details on sleep architecture limited the possibility of exploring the mechanisms underlying the observed variations. Third, the small sample size reduces statistical power and may limit the generalizability of the findings. Additionally, the study was conducted in a summer camp setting characterized by fixed routines, scheduled activities, and mandatory nocturnal glycemic checks. These organizational constraints may have influenced both physical activity levels and sleep continuity, representing an inherent limitation in interpreting causal relationships. Despite these limitations, the results obtained provide interesting insights for future research. Future studies should include follow-up periods to evaluate chronic adaptations in physical activity and sleep patterns. Furthermore, precise strategies to reduce sleep fragmentation and enhance sleep hygiene could further potentiate the observed benefits.

5.6 Conclusions

This study shows that children and adolescents with T1D have lower physical activity levels, more sedentary time, and lower sleep time compared to the recommendations provided by the international guidelines. Participation at a structured summer camp led to a great increase in daily physical activity, reduction in time spent in sedentary, and an improved sleep quality, even the total sleep time was lower than the baseline. These results highlight the importance of structured and enjoying context to promote healthy behaviors in youth with T1D. In particular, programs including regular physical activity, structured daily routines and natural environments could

contribute to improve general well-being and metabolic control in youth with T1D. Moreover, the study suggests that individual variations in physical activity may differentially influence sleep continuity, highlighting the need to further explore how movement behaviors interact with sleep regulation in youth with T1D. Future studies should focus long-term effects and the role of the circadian regulation to further optimize these interventions.

**6. STUDY 4: Step-Based Physical Activity and Glucose
Dynamics in Youth with Type 1 Diabetes During a
Structured Summer Camp**

6.1 Introduction

Type 1 diabetes (T1D) is a chronic autoimmune condition in which the destruction of pancreatic β -cells leads to reduced endogenous insulin production and persistent hyperglycemia. As a consequence, individuals with T1D require lifelong exogenous insulin therapy to maintain glycemic control ¹²¹. Managing T1D during childhood and adolescence is particularly challenging due to fluctuations in insulin sensitivity, ongoing physiological maturation, behavioural variability, emotional instability and irregular daily routines ^{81,122}. Physical activity (PA) represents a key component of pediatric diabetes care. Indeed, the practise of regular exercise improves insulin sensitivity, enhances glucose uptake, reduces cardiovascular risk and supports psychological well-being. For these reasons, the International Society of Pediatric and Adolescent Diabetes (ISPAD) emphasizes the need to educate young people with T1D about the metabolic effects of exercise and recommends integrating PA monitoring into clinical follow-up ⁸¹. Children and adolescents with T1D often engage in lower levels of PA than their healthy peers, partly due to concerns about hypoglycemia and the difficulty of balancing exercise with insulin dosing. Such behavioural constraints may influence overall metabolic control and contribute to day-to-day variability in glycemic patterns ⁸⁷. Diabetes summer camps offer a unique naturalistic, structured and interesting environment to observe the interaction between behaviour and glycemic fluctuations providing, also, standardized meals, scheduled activity sessions and continuous clinical supervision. Previous studies have reported improved glycemic control, reduced glycemic variability and enhanced self-management skills among participants during summer camps ^{123,124}, although existing some methodological limitations. First, objective PA monitoring is rarely implemented. When PA is described, it is typically reported in qualitative terms (e.g., “sports” or “recreational activities”), without information on duration, intensity or temporal structure. Second, none of the available studies has examined PA as a quantitative predictor within glucose forecasting models, not allowing a deeper understanding of how daily objective PA influenced metabolic trends. These represent a clear gap in the literature, especially considering the widespread availability of wearable devices capable of continuous movement tracking. Wrist-worn accelerometers offer high-resolution, continuous data that can be used to derive different

behavioural outcomes, including activity counts, activity intensity and step accumulation ¹²⁵. Among these, step based metrics are particularly useful to determinate ambulatory activity, showing that step counts from wrist-worn accelerometers explain a substantial proportion of variance in accelerometry-based estimates of light, moderate and vigorous PA in both children and adults ¹⁷. Commercial devices such as Fitbit provide minute-by-minute step data, whereas intensity-based variables are only available as aggregated of daily minutes. This distinction is methodologically relevant because intensity classifications lack universal standardization across devices, populations and age groups, and may thus introduce misclassification bias ^{126,127}. In contrast, step counts provide a device-agnostic, continuous behavioural measure well suited for alignment with physiological time series collected at irregular intervals, such as manually recorded capillary glucose values. In children and adolescents with T1D, blood glucose often shows wide and rapid fluctuations driven by behavioural, hormonal, and physiological factors, resulting in highly variable and frequently non-linear glycemic patterns ¹²⁸. Given this high intra-individual variability, statistical frameworks that explicitly model repeated measurements within the same child are necessary before exploring more flexible non-linear structures. In pediatric diabetes research, several studies have employed longitudinal modelling frameworks to describe metabolic trajectories, such as BMI change or glycemic control, using mixed-effects approaches that incorporate both fixed effects and subject-specific variability ^{129,130}. Building on this methodological foundation, more flexible approaches such as Generalized Additive Mixed Models (GAMM) extend these frameworks by modelling non-linear relationships while still accounting for the marked intra-individual variability typical of youth with T1D. GAMMs combine smoothing functions with random effects, making them particularly suitable for capturing complex, non-linear glycemic fluctuations ¹³¹. However, no studies to date have applied GAMMs to model short-term glycemic dynamics in children and adolescents with T1D, nor to examine the association between physical activity, or accelerometer-derived metrics such as step counts, and fingerstick glucose values. In addition to modelling the association between behavioural and metabolic variables, glucose can also be examined from a forecasting perspective, which represents a distinct analytical objective. Within this predictive domain,

Autoregressive Integrated Moving Average (ARIMA) models have been widely used in diabetes research, demonstrating good short-term prediction accuracy and showing effective early detection of hypoglycemia^{132–134}. Previous studies applying ARIMA models for glucose forecasting have predominantly used continuous glucose monitoring (CGM) data, whereas no work has examined ARIMA-based forecasting using capillary fingerstick glucose. Although CGM systems provide continuous data, they estimate glucose from interstitial fluid rather than blood, resulting in physiological lag and lower accuracy compared with capillary blood glucose measured by fingerstick^{135,136}. Given these considerations, the aims of the study were: (i) to evaluate the association between steps taken and blood glucose levels using a within subjects linear regression, (ii) to describe glucose trajectories across the 10 days of camp using an analysis of variance, (iii) to model the association between glucose and carbohydrate intake (cho), insulin adjustment (ins.adj), and step-based activity using both linear mixed-effects models (LMMs) and GAMMs while accounting for repeated measures; and (iv) to test whether adding step-based activity features improves individualized glucose forecasting performance compared with models using cho and ins.adj alone, using ARIMA-based forecasting with exogenous regressors.

6.2 Materials and Methods

6.2.1 Participants and Camp Structure

Thirty children and adolescents, 15 boys and 15 girls (mean age 13.35 ± 1.89), diagnosed with T1D were recruited from the Pediatric Clinic of the Ippokratio General Hospital in Thessaloniki, Greece, where they are routinely followed for diabetes management. Most participants had previously completed the baseline measurements described in Study 3, while four children did not take part in the baseline phase but were enrolled directly into the present study. The sample size was determined by the number of eligible participants attending the camp and should be considered pragmatic. During the last two weeks of July, participants and their families visited the Pediatric Unit of the Ippokratio General Hospital for routine clinical evaluations and preparatory procedures. During these visits, families received standardized instructions on device usage, account creation, and synchronization procedures to ensure consistent data acquisition

throughout the study period. From the final days of July, participants attended a 10-day Diabetes Summer Camp organized by the YMCA (Young Men’s Christian Association) in Chalkidiki, Greece. The camp offered a highly structured daily routine including morning and afternoon PA sessions, recreational programs, educational workshops and communal meals, all conducted under continuous clinical supervision. A summary of participants’ demographic and clinical characteristics are presented in Table 12.

The study was conducted in accordance with the Declaration of Helsinki and approved by the Scientific Committee of the Ippokratio General Hospital (protocol code: 33475/19-7-2024). Written informed consent was obtained from parents or legal guardians prior to participation, and assent was obtained from children when appropriate.

Table 12. Demographic and clinical characteristics of the participants during the camp.

Variable	Mean $\pm$ SD	Minimum	Maximum
Age (years)	13.35 $\pm$ 1.89	9.77	17.44
BMI (z-score)	0.66 $\pm$ 1.34	−1.71	4.46
HbA1c (%)	7.13 $\pm$ 1.18	5.90	12.50
AVG Glucose (mg/dl)	156.86 $\pm$ 19.14	117.38	195.42
AVG cho (g)	266.69 $\pm$ 44.03	171.65	347.26
AVG ins.adj (UI)	15.53 $\pm$ 6.35	4.20	27.60

Summary statistics are presented as mean and $\pm$ standard deviation (SD). BMI: Body Mass Index; z-score: number of SDs from the mean; HbA1C: Glycated Hemoglobin; %: percentage; AVG: Average; mg/dl: milligrams per deciliter; cho: carbohydrates intake; g: grams; ins.adj: insulin adjustments; UI: International Unit.

2.4 Camp structure and daily schedule

The summer camp was held in a large natural environment located at high altitude, with direct access to the sea, situated at the Chalkidiki peninsula, in Greece. The camp’s structure encouraged continuous movement throughout the day, as participants had to walk between the different areas where activities, meals, and sleep accommodations were located. The daily program was

organized into three main physical activity sessions, two in the morning and one in the afternoon, which included swimming, basketball, volleyball, climbing, and other recreational and educational games. In addition, campers participated in collective routines and leisure moments that further contributed to overall daily movement. A typical daily schedule of the camp is presented in Figure 4 in Study 3, showing the structured alternation of physical activities, meals, rest, and recreational periods.

6.2.2 Glycemic Monitoring and Daily Clinical Procedures

Glycemia was assessed through capillary fingerstick measurements performed by clinical staff and recorded manually on dedicated paper sheets. Seven measurements were conducted daily. Participants were awakened around 07:30–07:45 to undergo the first glucose check at 08:00, followed by the declaration of the intended breakfast intake and ins.adj. After consumption, participants returned if needed to correct discrepancies between planned and actual intake. The second glucose check occurred around 11:15, after the first morning activity session (10:00–11:15). The third measurement was performed before lunch (~13:00), during which meals were visually presented and cho declared before ins.adj. Afternoon rest was followed by a fourth measurement (~16:45), then a snack and a second activity session (17:00–18:30). The fifth measurement occurred before dinner at 19:00. Evening recreational events were followed by a sixth measurement around 23:00, delaying bedtime. The seventh measurement occurred during the night (typically from 01:30 onwards), but the exact timing varied because the medical staff had to move between distant rooms; completing all night checks required at least 30 minutes. This timing variability is an inherent methodological limitation and is discussed later.

6.2.3 Step-Based Physical Activity Monitoring and Dataset Structure

According to their age, the participants wore two wrist-worn Fitbit devices (Fitbit Inc., San Francisco, CA, USA): the Fitbit Ace 3 and the Fitbit Inspire HR, assigned, throughout the camp^{107,108}. Most participants already possessed the device from the baseline monitoring phase conducted prior to camp arrival, whereas four children received their Fitbit between days 1 and 3, depending on their arrival date. Devices recorded step count at one-minute resolution

continuously. When needed, Fitbits were recharged during the afternoon rest period; across the entire 10-day camp, each participant required at most one recharge, and no additional device removals were scheduled. Minute-level step count files were extracted from the device's global export, which included a dedicated "*step_counts*" folder containing raw step values recorded for each minute of wear time. These files were imported into Excel and merged with the manually recorded clinical sheets. For each participant, minute-level step counts were aggregated to compute the total number of steps accumulated between two consecutive fingerstick glucose measurements. For example, the step value associated with the 19:00 glucose check represented the sum of all steps recorded between the preceding measurement (e.g., 16:45) and 19:00. The resulting dataset included the following variables: participant ID, date and timepoint of measurement, glucose value, cho, ins.adj, and interval step count. This dataset was then imported into R for statistical and forecasting analyses.

6.2.4 Statistical Analysis

Statistical analyses were performed using R (RStudio, version 4.3.0). Prior to modelling, descriptive and preliminary analyses were conducted to explore the relationship between physical activity and glucose levels and to characterize temporal glucose trends during the camp. A preliminary assessment was conducted for explorative purposes. It was analyzed the association between interval step count and glucose values using within subject linear regression using the package *rmcorr*, while a repeated-measures analysis of variance (ANOVA) was performed on a linear model including time and scaled steps as fixed factors, and their interaction, to assess longitudinal changes in glucose levels, using the package *rstatix*. Effect sizes were computed using generalized eta squared (η^2). Moreover, to assess the suitability of a random subject effect, a mixed-effects model was fitted to estimate the ICC. The ICC was low (0.07), indicating minimal between-subject heterogeneity, consequently, the random effect was unnecessary, and a fixed-effects ANOVA was sufficient. To facilitate model estimation and interpretation given the different measurement units (mg/dL for glucose, grams (g) for cho, ins.adj units (u), and step counts), cho, ins.adj, and interval step counts were z-standardized (centred and scaled to unit

variance using R base package) prior to the next analysis. To account for the data structure, characterized by repeated glucose measurements within participants, LMMs were fitted using R package *lme4*. Cho, ins.adj and time were added to the Model 1 as fixed-effect covariates, whereas glucose was the dependent variable and the participants as random effect. In the Model 2, interval step count and its interaction with time were included. Models comparisons were performed using likelihood ratio tests based on chi-square statistics. To investigate potential non-linear relationships between glucose levels and time while accounting for within-subject dependency, GAMM were also applied using R package *mgcv*. These models included a smoothing function for time and a random effect for participants. Specifically, time (in days) was modeled using a cubic regression spline with 9 degrees of freedom, while participant-specific variability was modeled via a random intercept.. Two model specifications were compared: one including cho and ins.adj (Model 1 GAMM), and a second model that additionally included step count (Model 2 GAMM). Model fit was compared using analysis of deviance. Finally, glucose was also analysed from a forecasting perspective applying ARIMA models using R package *forecast*. Individual time series were constructed for each participant, and two models were fitted per participant: the first included cho and ins.adj as external regressors, while the second additionally included step count. All variables entered into the ARIMA models were standardized during preprocessing to ensure comparability across predictors expressed in different units. Forecasting accuracy was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), and differences in forecasting performance between models were assessed performing paired t-tests using R package *rstatix* after checking normality assumptions using the Shapiro-wilk test. Statistical significance was set at $p < 0.05$.

6.3 Results

6.3.1 Preliminary Analyses

The linear regression showed no evidence of an association between glucose and step counts ($r = -0.013$, $p = 0.55$). In contrast, ANOVA revealed a significant but little increase in glucose across the observation period ($F(1,1917) = 15.87$, $p < .001$, $\eta^2 = 0.008$). There was no main effect of

steps on glucose ($F(1,1917) = 0.49, p = .485, \text{ges} < .001$), nor a significant steps $\times$ time interaction ($F(1,1917) = 1.61, p = .205, \text{ges} = .001$). Figure 6 displays glucose measurements over time with interval step counts represented as a continuous covariate, highlighting substantial variability and a modest temporal trend.

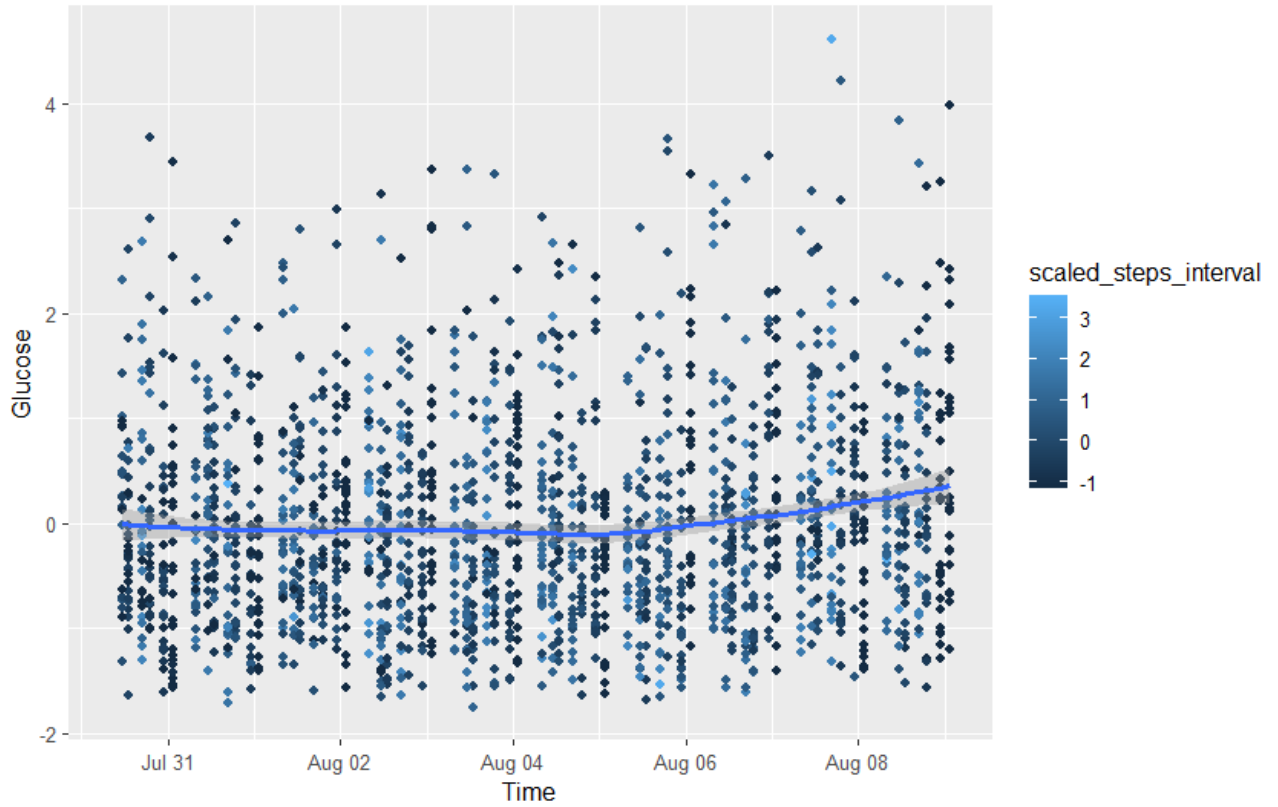


Figure 6. Longitudinal glucose measurements plotted over time. Step count during the prior interval is shown as a continuous color gradient. The solid curve represents a smoothed time trend.

6.3.2 Linear Mixed-Effects Models (LMMs)

The unconditional means model yielded an intraclass correlation coefficient (ICC) of 0.31. When time (expressed in hours since the first camp measurement) was included as a fixed effect with participant-specific random slopes, a significant association between time and glucose was observed ($\beta = 0.08, p = 0.003$). The linear mixed-effects model including cho, ins.adj, and time showed significant fixed effects for cho ($\beta = -42.53, p < 0.001$), ins.adj ($\beta = 50.90, p < 0.001$), and time ($\beta = 0.10, p = 0.008$). The marginal R^2 was 0.33 and the conditional R^2 was 0.54. Adding interval step count and its interaction with time did not significantly improve model fit ($\chi^2 = 1.32, p = 0.52$). In this model, the main effect of step count ($\beta = 2.70, p = 0.39$) and the interaction

between step count and time ($\beta = -0.02$, $p = 0.33$) were not statistically significant. Model details are reported in Table 13.

Table 13. Linear mixed-effects models with glucose levels as dependent variable.

Model 1 LMM: cho + ins.adj + Time				Model 2 LMM: cho + ins.adj + Time + Steps		
Predictor	β	95% CI	p	β	95% CI	p
(Intercept)	152.43	135.63 – 169.22	<0.001	152.17	135.86 – 168.47	<0.001
scaled_cho	-42.53	-46.51 – -38.56	<0.001	-42.64	-46.63 – -38.64	<0.001
scaled_ins.adj	50.90	46.58 – 55.22	<0.001	50.88	46.56 – 55.21	<0.001
scaled_steps				2.70	-3.46 – 8.87	0.390
time (h)	0.10	0.02 – 0.17	0.008	0.10	0.03 – 0.17	0.005
scaled_steps x time				-0.02	-0.07 – 0.02	0.331
Random Effects	Model 1	Model 2				
σ^2	2236.58	2240.86				
τ_{00}	1952.15 _{id}	1822.86 _{id}				
τ_{11}	0.03 _{id.time_h}	0.02 _{id.time_h}				
ρ_{01}	-0.87 _{id}	-0.87 _{id}				
ICC	0.31	0.30				
N	30 _{id}	30 _{id}				
Observations	1163	1163				
Marginal R ² /	0.331 /	0.334 /				
Conditional R ²	0.536	0.531				

Carbohydrate intake, insulin adjustment, and step count were z-standardized. LMM: Linear mixed-effects model; β : fixed-effect estimates; CI: Confidence interval; h: hours; σ^2 : sigma squared; τ_{00} : tau zero-zero; τ_{11} : tau one-one; ρ_{01} : rho zero-one; ICC: Intraclass Correlation Coefficient; N: number; R^2 : Coefficient of Determination.

6.3.3 Generalized Additive Mixed Models (GAMMs)

Generalized additive mixed models were fitted including cho, ins.adj, and a smooth term for time (hours since the first camp measurement). In Model 1, the smooth term for time was statistically significant ($p < 0.001$), and significant linear effects were observed for cho ($p < 0.001$) and ins ($p < 0.001$). The addition of interval step count in Model 2 did not result in a statistically significant improvement in model fit ($F = 1.03$, $p = 0.32$). In this model, the linear effect of step count was not statistically significant ($\beta = 1.69$, $p = 0.31$). The smooth term for time remained statistically significant ($p < 0.001$). Model details are reported in Table 14.

Table 14. Generalized Additive Mixed Models with glucose levels as dependant variable.

Model 1 GAMM cho + ins.adj + time				Model 2 GAMM: cho + ins.adj + time + steps		
Predictor	β	95% CI	p	β	95% CI	p
(Intercept)	167.13	161.48 – 172.77	<0.001	166.55	160.86 – 172.2	<0.001
scaled_cho	-36.05	-40.02 – -32.08	<0.001	-35.93	-39.91 – -31.96	<0.001
scaled_in.adj	38.37	34.44 – 42.29	<0.001	38.34	34.41 – 42.27	<0.001
scaled_steps				1.69	-1.59 – 4.98	0.312
smooth term (time h)			<0.001			<0.001
smooth term (ID)			0.050			0.057
Observations	1163			1163		
R^2	0.271			0.272		

Carbohydrate intake, insulin adjustment, and step count were z-standardized. GAMM: Generalized Additive Mixed Models; β : fixed-effect estimates; CI: Confidence interval; h: hours; ID: Participant Identifier; R^2 : Coefficient of Determination.

6.3.4. ARIMA Forecasting Models

ARIMA models were successfully fitted for 28 participants. Across participants, models including cho and ins.adj showed a mean RMSE of 0.61 ± 0.15 and a mean MAE of 0.48 ± 0.11 . When interval step count was included as an additional exogenous regressor, forecasting accuracy improved, with mean RMSE decreasing to 0.58 ± 0.14 and mean MAE decreasing to 0.46 ± 0.11 . Paired t-tests indicated that the reductions in RMSE ($t(27) = 3.67, p = 0.001$) and MAE ($t(27) = 3.27, p = 0.003$) were statistically significant. Figures 7 and 8 show the glucose forecasts generated by the two ARIMA models, with and without the inclusion of interval step as an external regressor. Figure 9 shows the comparison of RMSE and MAE between the two models across participants.

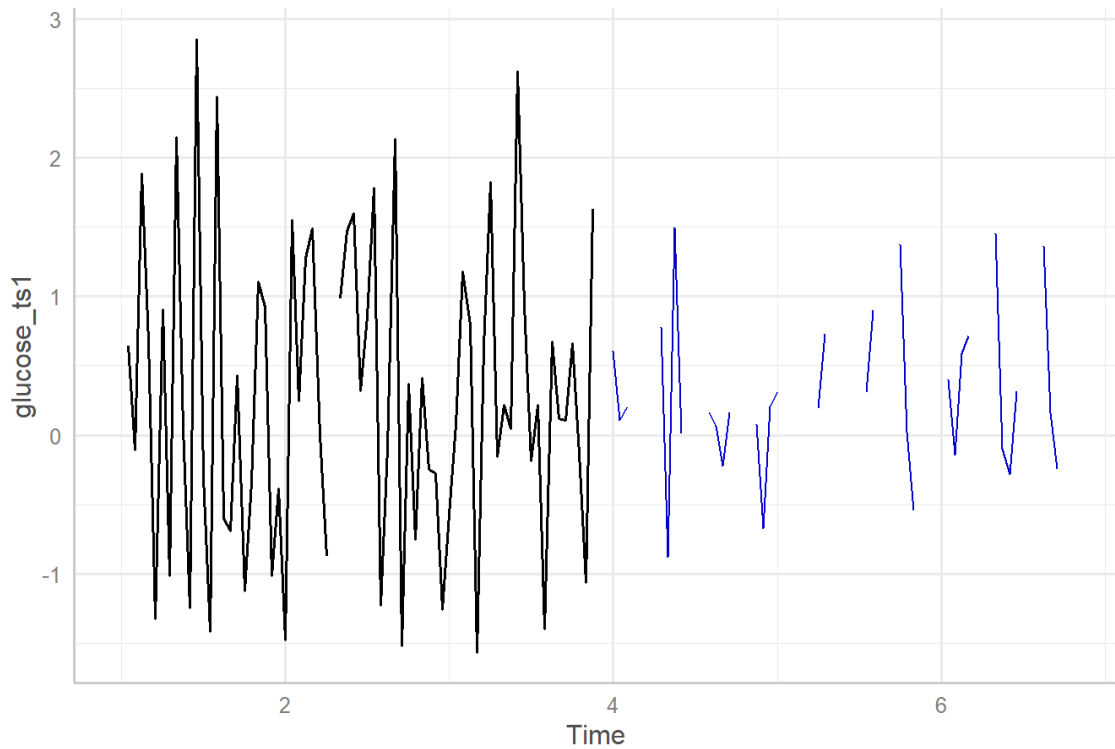


Figure 7. Glucose forecasting (blue line) using an ARIMA model with carbohydrate intake and insulin adjustments (Model 1).

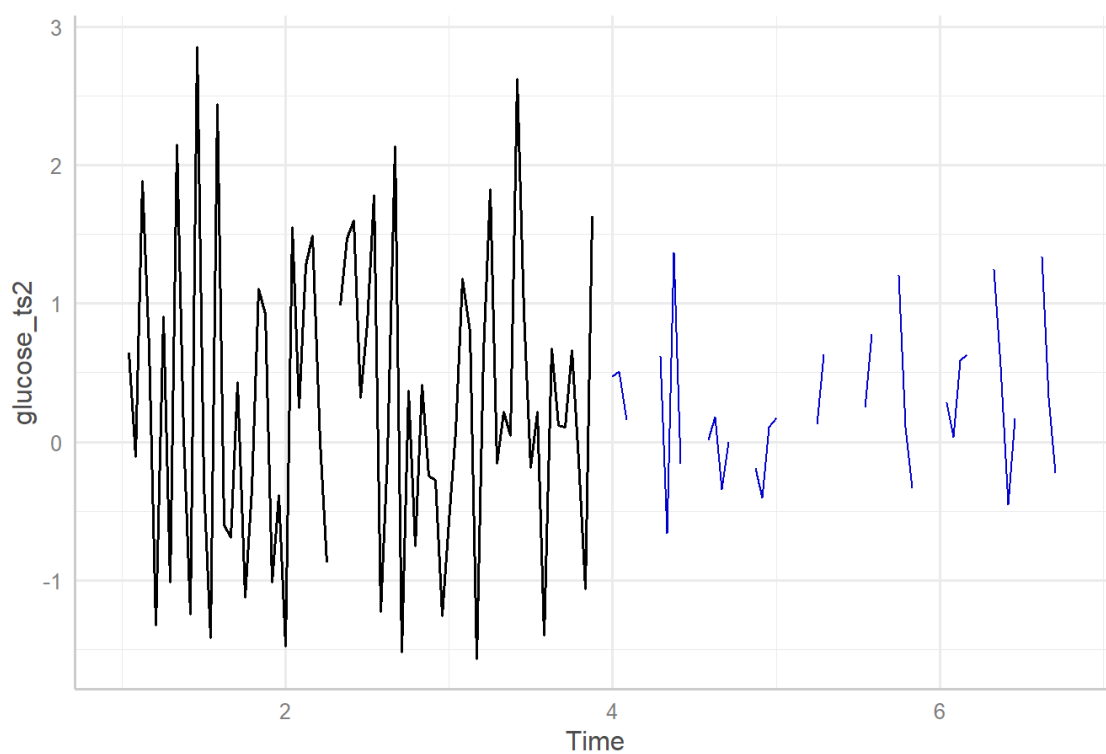


Figure 8. Glucose forecasting (blue line) using an ARIMA model with carbohydrate intake, insulin adjustments and steps (Model 2).

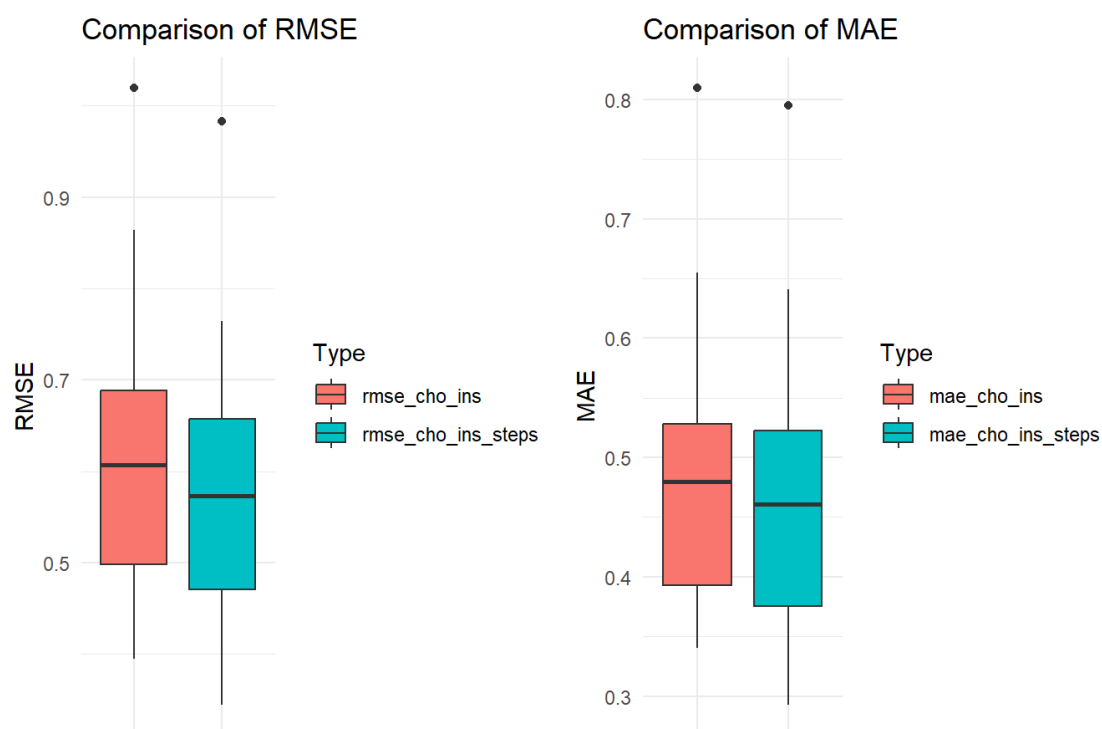


Figure 9. Comparison of glucose forecasting errors with and without step data. RMSE: Root Mean Square Error; MAE: Mean Absolute Error; cho: carbohydrate; ins.adj: insulin adjustment.

6.4 Discussion

This study examined the association between step-based physical activity and glycemic dynamics in youth with T1D during a structured 10-day summer camp. Three main findings emerged. First, step counts were not significantly associated with capillary glucose levels in either preliminary analyses or in linear and generalized mixed-effects models. Cho intake and ins.adj remained the dominant predictors of capillary glucose, consistent with the central role of post-prandial glucose excursions and insulin dosing in pediatric diabetes management. Second, glucose trajectories exhibited marked temporal fluctuations throughout the camp, and modelling approaches capable of accounting for intra-individual dependence and non-linearity improved the characterization of glycemic patterns compared with preliminary analyses. Third, despite the absence of significant linear associations, the inclusion of step counts enhanced forecasting performance in individualized ARIMA models, indicating that motor behaviour contributed to predictive accuracy. The lack of a contemporaneous association between step accumulation and capillary glucose is physiologically plausible. In the short term, glycemic responses to physical activity in youth with T1D are highly variable and depend on factors such as pre-exercise glucose levels, insulin on board, counter-regulatory hormones, and the timing and composition of meals¹³⁷. Therefore, the metabolic impact of activity may depend more on context than on the absolute number of steps accumulated in a given interval, reducing the likelihood of observing linear relationships in observational analyses. Moreover, activity-induced glucose changes may manifest with temporal delays that are not detectable through pointwise capillary measurements^{135,138}. It should also be considered that step count is primarily a volume-based metric that only partially reflects activity intensity. Although a higher number of steps per unit of time may indicate a higher average intensity, longer aggregation windows may fail to capture short high-intensity bouts within the same interval. For the same accumulated number of steps, different intensity profiles may therefore arise, potentially reducing the sensitivity of step-based metrics to detect metabolic or physiological effects.¹³⁹ These mechanisms may explain why step counts did not emerge as significant predictors in GAMM models, in contrast to cho intake and ins.adj, which reflect more direct determinants of acute glycemic excursions¹⁴⁰. These

considerations align with the behavioral and ecological patterns observed during the camp. Table 12 reports the metabolic and behavioral parameters of the participants during the camp, highlighting between-subject differences in daily carbohydrate intake and insulin adjustments as documented by the minimum–maximum intervals and standard deviations. Such between-subject differences are compatible with a setting characterized by structured meals, repeated post-prandial glucose checks and supervised insulin dosing. The pronounced intra-day variation in glucose, cho and ins.adj can be partly attributed to the daily organization of the camp (Study 3), which included scheduled physical activity sessions, communal meals and recreational events that occurred in close temporal proximity. The camp environment may also have influenced participants' habitual movement levels. As described in Study 3, the camp was located at altitude and extended across a large area, requiring walking between sleeping quarters, dining facilities, glucose monitoring stations and activity spaces throughout the day. In addition to these environmental factors, behavioral heterogeneity contributed to both within- and between-subject variability. Although physical and recreational activities were scheduled, participation was not mandatory, and participants differed in attendance, engagement and duration. Likewise, despite standardized meal offerings, children could adjust food quantities and, in some cases, consume additional snacks during free time. Figure 10 illustrates the day-to-day variation observed in one participant, showing fluctuations in glucose, carbohydrate intake and insulin adjustments across camp days. These trajectories appeared largely aligned for glucose, carbohydrate intake and insulin adjustments. In contrast, step accumulation showed more limited variation between days. As previously discussed, step count represents an absolute metric that only partially reflects activity intensity and may therefore not fully capture the behavioral and physiological components associated with glycemic fluctuations.

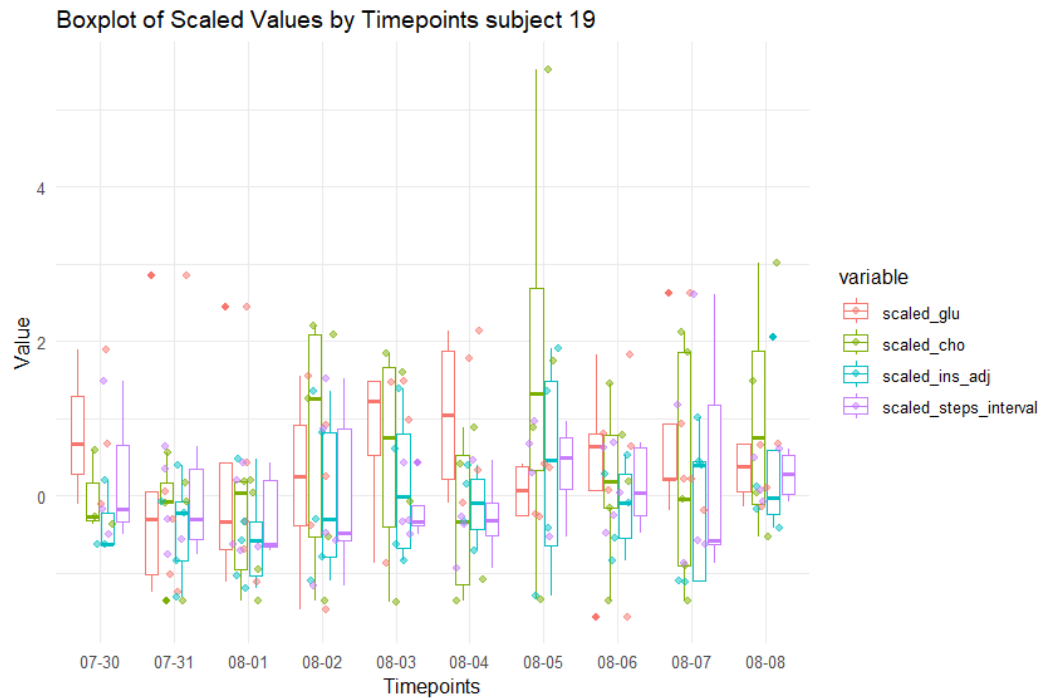


Figure 10. day-to-day variation in glucose level, carbohydrates intake, insulin adjustment and steps observed in one participant

When shifting from association-based analyses to a forecasting perspective, behavioural information contributed additional predictive value. In ARIMA models, the inclusion of step counts significantly reduced RMSE and MAE relative to models relying solely on cho intake and ins.adj. Unlike regression, forecasting models do not require variables to exert linear or contemporaneous effects; instead, they exploit temporal structure and conditional dependence within the series^{141,142}. In this context, step counts may encode aspects of daily behavioural rhythm, energy expenditure and activity-induced metabolic variability that, although not directly correlated with end-of-interval glucose levels, can enhance short-term predictive performance. These findings suggest that physical activity may support personalized glucose forecasting even in the absence of significant linear associations. The summer camp setting represents a favourable context for interpreting these findings, as daily routines were highly organized: meals, ins.adj and structured physical activities were programmed and supervised. This level of standardization reduced uncontrolled variability and facilitated the observation of glycemic fluctuations. At the same time, the camp did not constitute an artificial environment, as participants moved, played and ate naturally, as in everyday life. This balance between control and ecological behaviour

enabled the analysis of metabolic dynamics under clinically relevant conditions. The use of capillary fingerstick glucose measurements rather than CGM allowed for precise temporal alignment and avoided the physiological lag associated with interstitial fluid^{135,138}. This temporal alignment was essential for integrating minute-level step data and characterizing short-term glycemic fluctuations in youth with T1D.

This study also presents different methodological strengths. Data were collected in a real-world ecological setting, allowing metabolic and behavioural dynamics to unfold naturally during daily routines¹⁴. Glucose was measured using capillary fingerstick assessments, providing direct blood glucose values without the physiological delay associated with interstitial measurements¹³⁶. The protocol included several standardized glucose checks per day, offering a relatively dense temporal sampling of glycemic patterns and enabling the comparison of glucose responses across meals, activity sessions and nocturnal periods. PA was monitored objectively through wearable devices, reducing dependence on self-report, which is particularly unreliable in children and adolescents¹²⁵.

6.5 Limitations

Despite the methodological strengths, some limitations should be acknowledged. Fingerstick measurements provide precise temporal anchoring but yield lower sampling density compared with CGM. Although ARIMA models handled these irregular series, denser sampling or the combined use of CGM would enable a better characterization of delayed or non-monotonic activity effects. Step counts quantify ambulatory movement but do not capture intensity, modality or anaerobic effort, which may affect glucose through distinct physiological pathways. The camp setting increases internal validity but limits generalizability to less structured environments. Finally, the sample size, constrained pragmatically by camp enrollment, warrants replication in larger cohorts. Despite these limitations, the results contribute to an emerging literature examining behavioural signals as predictors of short-term glycemic dynamics in youth with T1D.

6.6 Conclusions

These findings highlight the importance of distinguishing between associative and predictive domains and suggest that step-based metrics may hold value for personalized glucose forecasting even in the absence of linear associations. Future work should examine whether integrating richer accelerometry features, hormonal or contextual information, or CGM-based glycemic series can further improve predictive performance under free-living conditions.

**7. STUDY 5: From Feasibility to Field Application:
Nocturnal Heart Rate Monitoring in Adolescents With
Type 1 Diabetes During a Summer Camp**

7.1 Introduction

Resting heart rate (HR) represents a robust physiological marker associated with autonomic balance, cardiorespiratory fitness, and recovery capacity^{143,144}. Nocturnal HR, in particular, offers unique advantages for physiological monitoring since it is measured in an artifact-free context, reflects parasympathetic reactivation during sleep, and is sensitive to training-induced adaptation^{145,146}. In healthy individuals, sleep is typically characterized by a physiological reduction in HR compared to daytime values, a phenomenon referred to as nocturnal HR dipping, which reflects normal circadian autonomic regulation. Blunted or absent nocturnal HR dipping (non-dipping) has been associated with adverse cardiovascular outcomes and increased mortality risk in adult populations, independently of daytime HR levels¹⁴⁷. In children and adolescents, autonomic regulation is still maturing, and evidence on nocturnal HR dipping remains limited and condition-specific. Available pediatric studies suggest that preserved nocturnal HR dipping is typical in healthy youth, whereas impaired dipping has been reported mainly in clinical populations characterized by autonomic or sleep-related disturbances, such as children with Down syndrome and sleep-disordered breathing¹⁴⁸. To date, however, nocturnal HR dipping has not been investigated in adolescents with Type 1 diabetes (T1D), nor in ecological intervention settings such as diabetes summer camps. Progressive reductions in nocturnal HR over consecutive days may therefore be interpreted not only as evidence of improved autonomic recovery, but also as the emergence or strengthening of a physiological nocturnal dipping pattern, reflecting enhanced parasympathetic activity and reduced sympathetic drive during sleep^{143,146}. Summer camps provide a unique, naturally structured intervention capable of modulating nocturnal HR through multiple converging mechanisms. These settings substantially increase daily physical activity (PA) levels in children and adolescents with chronic diseases, including moderate-to-vigorous physical activity (MVPA)^{96,97}, which is known to enhance cardiovascular fitness and parasympathetic tone^{149,150}. Moreover, camps are hosted in outdoor and nature-based environments, which may facilitate autonomic recovery and stress reduction through psychophysiological pathways^{29,32}. Finally, summer camps incorporate psychosocial factors such as peer support, reduced disease burden, playful routines, and emotional engagement, all of which

may contribute to reduced psychological stress and enhanced autonomic balance^{151,152}. These mechanisms are particularly relevant for children and adolescents with T1D, as daily management inherently involves behavioral complexity, psychological stress, and glycemic variability, all known to influence autonomic function^{153,154}. While PA is strongly recommended for pediatric T1D¹⁵⁵, barriers such as fear of hypoglycemia often limit participation⁴. Diabetes summer camps have been shown to increase PA, improve diabetes self-efficacy, and promote positive psychosocial adaptation in youth with T1D, making them an ideal ecological setting for physiological monitoring⁹⁸. Despite a growing body of literature on diabetes camps, most studies focus on psychosocial or educational outcomes, whereas physiological responses, particularly autonomic markers and nocturnal cardiovascular regulation, remain understudied. To date, no studies have longitudinally evaluated nocturnal HR or nocturnal HR dipping as potential indicators of physiological adaptation during diabetes summer camps, and no data exist using wearable devices to characterize nocturnal autonomic responses in this context. This represents an important gap, given the multimodal nature of camp-based interventions and the feasibility of measuring nocturnal HR through photoplethysmography (PPG). Wearable devices based on photoplethysmography (PPG) allow continuous HR recording in free-living conditions. PPG is an optical technique that enables estimation of HR by detecting changes in blood volume in peripheral microvasculature. PPG sensors emit light into the skin and measure variations in reflected light caused by blood pulsations with each heartbeat^{156,157}. Based on the rationale that increased PA, reduced stress, environmental exposure, and improved diabetes management may collectively enhance autonomic recovery and nocturnal cardiovascular regulation, the hypothesis of this study is that participation in a diabetes summer camp would lead to a progressive decrease in nocturnal HR throughout camp days. Accordingly, the aims of this study were to (i) evaluate the day-by-day trend in nocturnal HR across the duration of the camp, (ii) examine the association between nocturnal HR and nocturnal glucose levels, and (iii) separate the between-participant and within-participant components of nocturnal glucose.

7.2 Materials and Methods

7.2.1 Pilot study and definition of a signal quality criterion

Before applying continuous HR monitoring in the context of the Diabetes Camp, a pilot study was conducted on two healthy young adults with the aim of assessing how the Fitbit Inspire HR (Fitbit Inc. San Francisco CA, USA) recorded and exported HR data under free-living conditions. The Fitbit Inspire HR is a wrist-worn device that uses PPG for HR measurement. In this preliminary phase, the device was worn continuously for two consecutive days, both day and night, with the exception of short removal periods for showering. To evaluate the reliability and contextual plausibility of the HR signal in real-world settings, an activity diary was collected using a smartphone application (“Timestamp – Activity Tracker”, version 1.2.24). The application allowed participants to record the start and end of activities with a single click and to annotate the activity type (e.g., walking, sitting, sleeping, or device not worn). At the end of monitoring, diary data were exported in .csv format, while HR data were downloaded from Fitbit in .json format. The Fitbit HR export is organised by day and includes, for each observation, a timestamp (date and time), the HR value expressed in beats per minute (bpm), and a confidence value ranging from 0 to 3, which represents an internal signal quality indicator. The device samples HR every 5 seconds. Both datasets, diary and HR, were imported into R (RStudio 2025.05.1+513 "Mariposa Orchid") and timestamps were converted to a common format to enable temporal alignment. After synchronisation, the two data sources were merged into a single database. Temporal gaps in the HR series were preserved and made explicit through missing values (NA), ensuring a continuous time series and transparent visualisation of signal interruptions. HR data were then plotted over time and compared with the diary annotations. Figure 10 shows the raw HR time series aligned with diary annotations. Exploratory inspection revealed that, in time windows in which the diary clearly indicated that the device was not being worn, Fitbit continued to provide HR values that appeared physically implausible or inconsistent with the context. Importantly, such values consistently corresponded to confidence values of 0 or 1, whereas plausible HR values recorded when the device was actually worn predominantly

showed confidence values of 2 or 3. To visualise this relationship, HR data were plotted with colour coding by confidence level (0–3), as shown in Figure 11. Based on these observations, a signal quality criterion was defined: HR observations with confidence values of 0 or 1 were considered unreliable and excluded from further analyses, while data with confidence values of 2 or 3 were retained and interpreted as presumably valid. This criterion, derived from the pilot study, was subsequently applied systematically to the analysis of HR data collected during the Diabetes Camp.

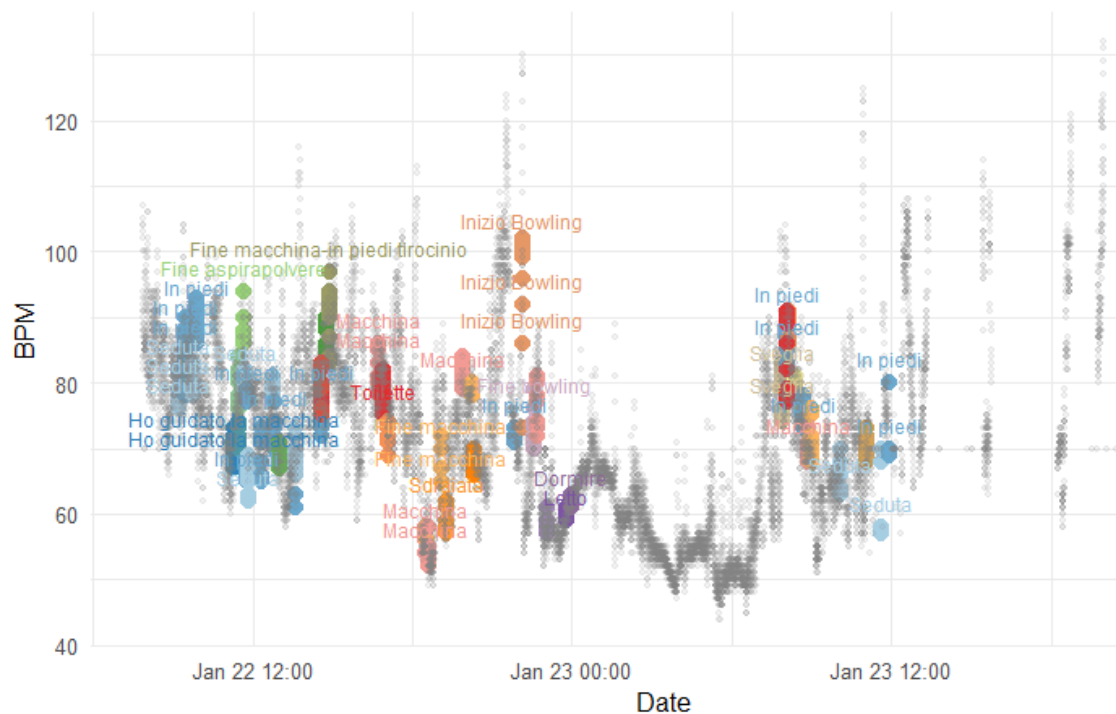


Figure 10. Raw HR time series aligned with log diary annotations during the pilot study.

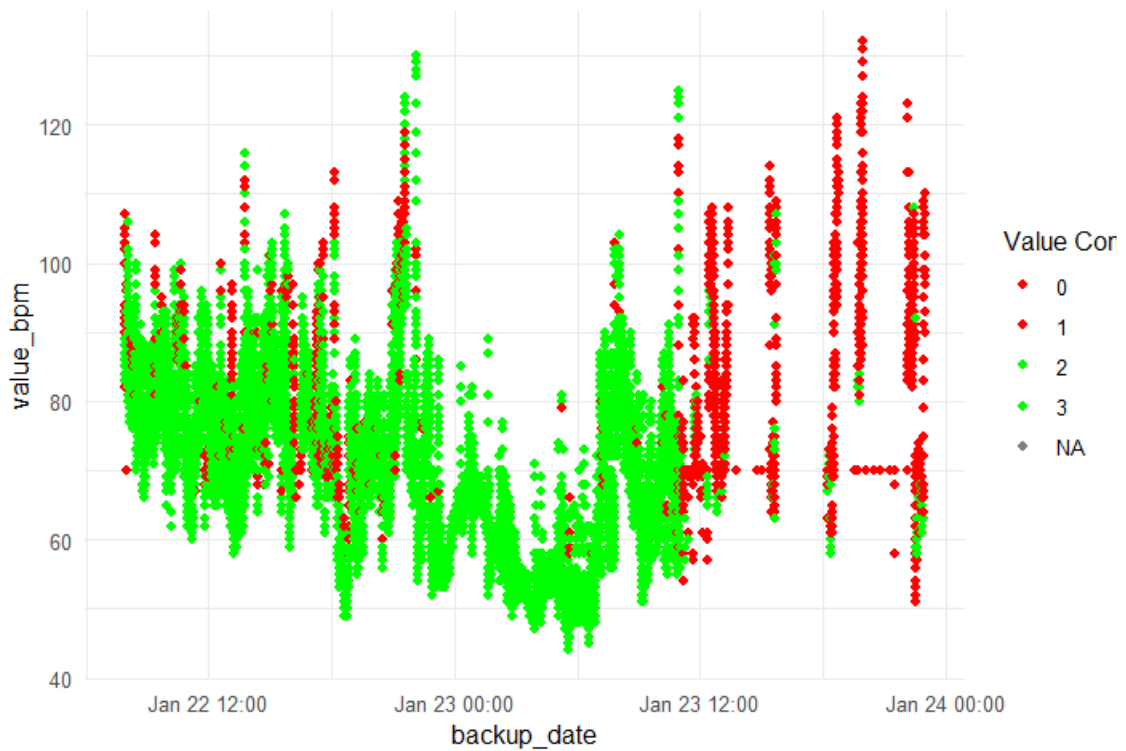


Figure 11. HR time series colour-coded by Fitbit confidence values (0–3).

7.2.2 Data collection during the Diabetes Camp

In the main phase of the study, the same approach was extended to a subgroup of participants from the Diabetes Camp for whom continuous HR monitoring via Fitbit Inspire HR was available. The subgroup consisted of 23 participants (14 males and 9 females; age: 14.96 ± 1.63 years; BMI z-score: 0.51 ± 1.29 ; HbA1c: $7.20 \pm 1.27\%$). As in the pilot phase, the device was worn on the wrist continuously throughout the 10-day camp period, including both daytime and nighttime, and was removed only for showering. Participants also wore the device during aquatic activities. Each device was recharged only once during the entire camp, typically during the afternoon nap, in order to minimise data loss. The structure of the camp, the organisation of daily activities and the timing of clinical assessments are described in detail in Studies 3 and 4. At the end of the camp, raw HR data were downloaded from each Fitbit device in .json format, with one file per day for each participant. The downloaded data were imported into R, transformed and organised such that each participant had a complete daily HR time series with date and timestamp information. For each day and for each participant, HR data were processed using the signal

quality filter defined in the pilot study, and temporal gaps were filled with missing values (NA) in order to standardize the time series, following the same procedure adopted in the pilot phase.

7.2.3 Definition of temporal segments and timepoints

Based on the daily organisation of the camp, each day was divided into six predefined temporal segments, identical for all participants:

- Night: 00:00–08:00
- Morning: 08:01–11:15
- Pre-lunch: 11:16–13:00
- Nap: 13:01–16:45
- Afternoon: 16:46–19:00
- Evening: 19:01–23:59

For each participant and for each day, HR observations were assigned to the corresponding segment according to their timestamp. Within each segment, two metrics were computed:

1. the mean HR in beats per minute (bpm)
2. the percentage of missing data, calculated as the proportion of timestamps within the segment for which HR was coded as NA.

To avoid unreliable estimates, a validity criterion was applied: if more than 70% of the observations within a segment were missing, the segment mean was considered invalid and set to NA. Each segment was also associated with a representative timepoint (e.g., 08:00 for Night, 11:15 for Morning, 13:00 for Pre-lunch, 16:45 for Nap, 19:00 for Afternoon and 23:59 for Evening), which allowed HR values to be integrated with other time-stamped variables (such as glucose, carbohydrates or insulin) in a long format dataset. In addition to segment means, a daily 10th percentile of daytime HR (08:00–23:59) was computed as an indicator of the lower end of daytime HR values. This percentile was estimated in two versions: one applying the same 70%

missingness threshold used for segments, and a second version using all available data, regardless of missingness, as a sensitivity check. Before proceeding with longitudinal modelling, segment-level completeness was examined to characterise the availability of HR data across daytime and nighttime periods. A heatmap summarising the proportion of valid observations per participant and segment (Figure 12) revealed substantial variability in daytime coverage, with several daytime segments exhibiting high missingness or complete signal absence, likely due to poor wear compliance, sunlight interference or motion artefacts. In contrast, the Night segment (00:00–08:00) showed consistently higher completeness and stability across participants. Based on this preliminary technical assessment, and to ensure comparable signal quality across subjects and days, formal statistical analyses were restricted to nocturnal HR. “Of the 23 participants who wore the Fitbit device during the camp, 21 had valid nocturnal HR data (Night: 00:00–08:00) for at least one day. Two participants showed 0% completeness in the Night segment and were therefore excluded from subsequent longitudinal analyses.

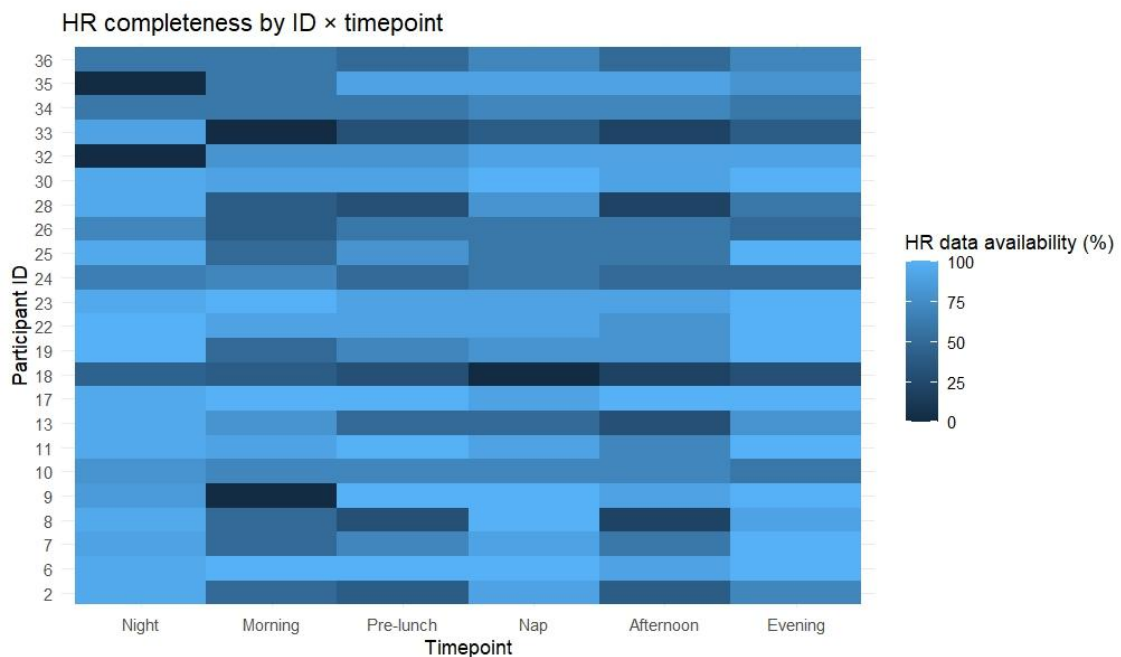


Figure 12. Percentage of available HR data by temporal segment and participant.

7.2.4 Construction of the nocturnal dataset and variables used in the models

For the longitudinal analyses of nocturnal HR, only the Night window (00:00–08:00) was considered. For each participant and for each camp day, the nocturnal mean HR was computed from the 5-second filtered series, following the quality control procedures and missing-data criteria described above. This value was then paired with the corresponding nocturnal glucose measurement obtained via fingerstick around 01:30, chosen as a representative timepoint during a relatively stable phase of sleep and sufficiently distant from the evening post-prandial period. Nights were indexed as “days” within the timeline of the camp: for each participant, the first validated night was assigned value 0, the next value 1, and so on. This indexing variable was subsequently centred to improve mixed-model estimation and the interpretability of coefficients. The resulting dataset was longitudinal, with each row representing a participant–night combination, and containing the following core information:

- Participant ID
- Reference date/time of the night
- Nocturnal mean HR
- Nocturnal glucose
- Relative camp day

7.2.5 Statistical analyses

The evolution of nocturnal HR throughout the camp was analysed using linear mixed-effects models, which account for both intra-subject variation (different days within the same participant) and inter-subject differences (baseline level and individual adaptation trajectories). In a first model, nocturnal mean HR was modelled as a linear function of centred camp day, including random intercepts and random slopes for each subject, in order to estimate the average temporal trend and the extent of individual variability around that trend. In a second model, the baseline structure was extended by adding nocturnal glucose as a time-varying covariate, expressed in units of 10 mg/dL (Glucose/10), along with its interaction with camp day, to test whether both the level of nocturnal glucose and its association with nocturnal HR varied over time. In a third model,

nocturnal glucose was decomposed into a between-subject component (each participant's mean nocturnal glucose across the camp) and a within-subject component (the nightly deviation from the participant's own mean). Interactions between camp day and both glucose components were included, allowing us to examine whether between-subject differences and within-subject fluctuations in glucose showed differential associations with nocturnal HR trajectories over the camp. Model estimation was performed using restricted maximum likelihood (REML). To evaluate whether the inclusion of nocturnal glucose terms improved model fit, nested model comparisons were conducted using maximum likelihood (ML), likelihood ratio tests, and information criteria (AIC and BIC). A p-value < 0.05 was considered statistically significant.

7.3 Results

7.3.1 Model 1 - Linear mixed-effects model without glucose

Nocturnal HR was analysed using a LMM including centred camp day as a fixed predictor, and random intercepts and random slopes by participant (Model 1). The model estimated a negative average temporal trend: higher camp days were associated with lower nocturnal HR values. The random-effects structure indicated the presence of substantial between-subject heterogeneity both in baseline HR levels and in individual slopes. The details are shown in Table 15.

Table 15. Model 1: nocturnal_HR ~ day_c + (day_c | ID)). Fixed effects of the mixed-effects model and variance components.

Predictor	Estimate	SE	df	p	95% CI
Intercept	72.09	1.65	20.17	<0.001	68.64 – 75.53
day_c	−0.61	0.24	21.48	0.021	−1.12 – −0.09
Random Effects					
σ^2	33.53				
τ_{00} ID	52.72				
τ_{11} ID.day_c	0.58				
ρ_{01} ID	−0.09				

Predictor	Estimate	SE	df	p	95% CI
ICC	0.63				
N _{ID}	21				
Observations	174				
Marginal R ² / Conditional R ²	0.027 / 0.640				

SE: standard error; df: degrees of freedom; CI: Confidence Interval; day_c: centred daily camp; σ^2 : residual variance; $\tau_{00 \text{ ID}}$: Intercept variance; $\tau_{11 \text{ ID.day_c}}$: Slope variance; $\rho_{01 \text{ ID}}$: Intercept-slope correlation; ICC: Intraclass Correlation Coefficient.

The distribution of participant-specific slopes showed that the majority exhibited negative slopes as specified in Table 16 and showed in Figures 13. Model-based predicted HR values visualised across relative camp days are reported in Figure 14.

Table 16. Model 1. Distribution of participant-specific slopes.

Statistic	Value
n participants	21
slope < 0	19
slope > 0	2
median slope	−0.62 bpm/day
minimum slope	−1.90 bpm/day
maximum slope	0.26 bpm/day

n: numbers; bpm: beats per minute.

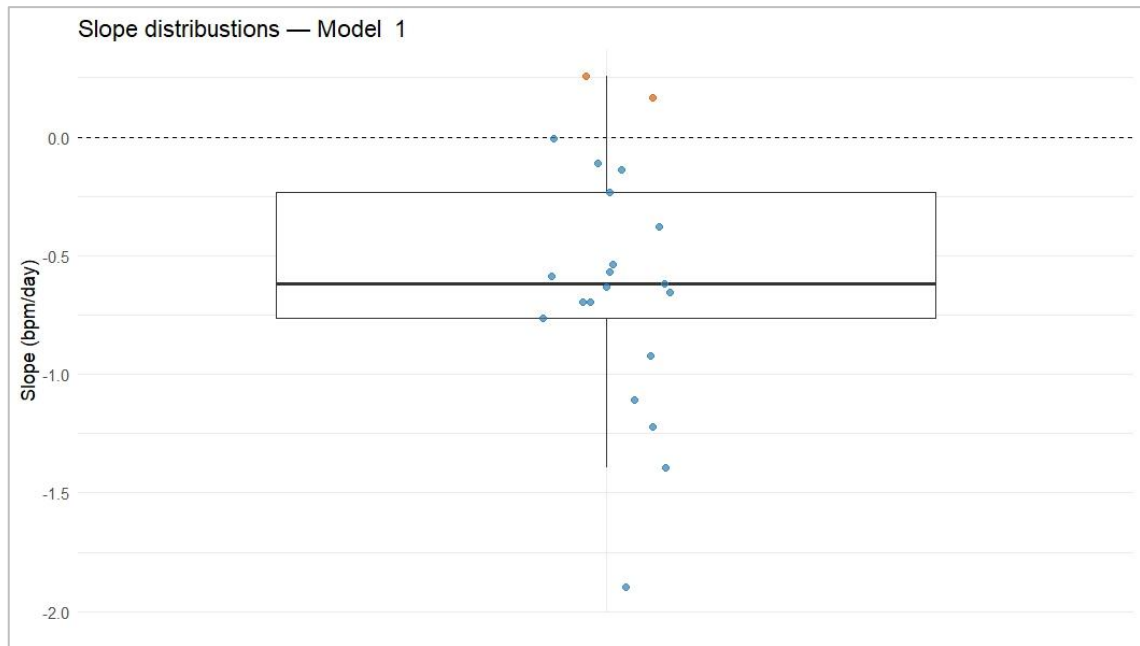


Figure 13. Model 1. Distribution of subject-specific slopes.

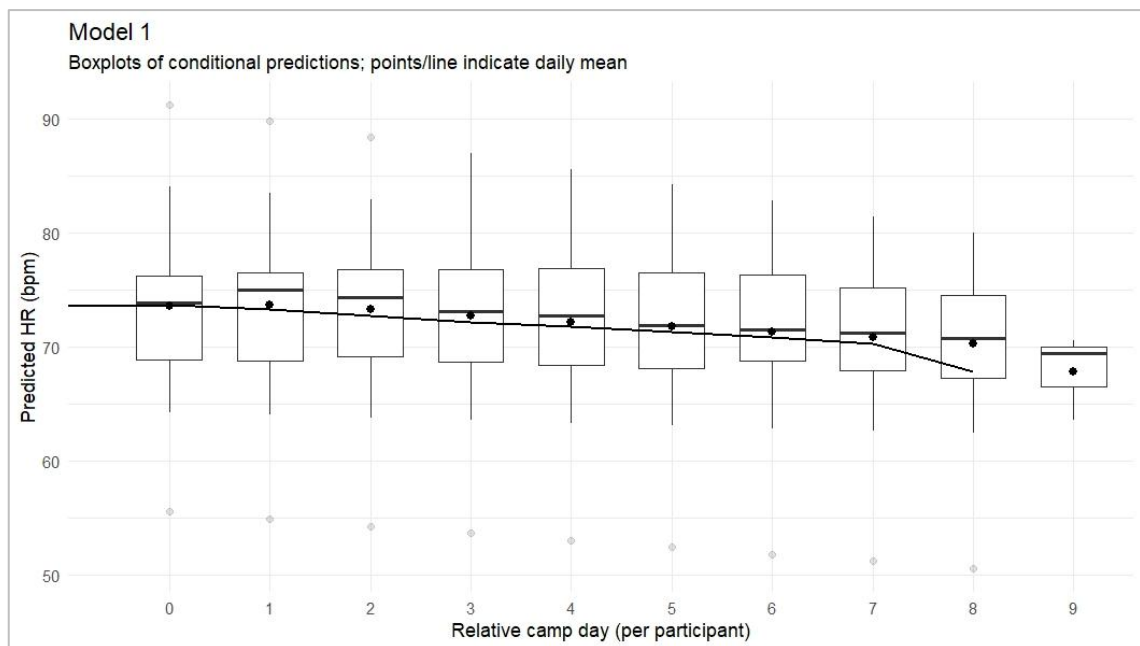


Figure 14. Model 1. Conditional predictions of nocturnal HR from the mixed-effects model without glucose across camp days.

7.3.2 Model 2 - Linear mixed-effects model including nocturnal glucose

Nocturnal HR was analysed using a linear mixed-effects model including centred camp day and nocturnal glucose as fixed predictors, along with their interaction (glucose scaled in units of 10 mg/dL), and random intercepts and random slopes for camp day by participant. As in Model 1,

the model estimated a negative average temporal trend, indicating lower nocturnal HR values with increasing camp days. Neither the main effect of nocturnal glucose (evaluated at the centred camp day) nor its interaction with camp day reached statistical significance, while variance components remained comparable to Model 1. Fixed-effects estimates and variance components are summarised in Table 17.

Table 17. Model 2: nocturnal_HR $\sim$ day_c + Glucose/10 + day_c $\times$ Glucose/10 + (day_c | ID). Fixed effects and variance components.

Predictor	Estimate	SE	df	p	95% CI
Intercept	70.83	2.06	46.27	<0.001	66.74 – 74.91
day_c	−0.35	0.48	105.20	0.466	−1.32 – −0.61
Glucose/10	0.08	0.07	147.14	0.311	−0.08 – 0.24
day_c * Glucose/10	−0.01	0.02	150.30	0.554	−0.07 – 0.04
Random Effects					
σ^2	33.63				
τ_{00} ID	53.13				
τ_{11} ID.day_c	0.57				
ρ_{01} ID	−0.09				
ICC	0.63				
N _{ID}	21				
Observations	174				
Marginal R ² / Conditional R ²	0.032 / 0.642				

SE: standard error; df: degrees of freedom; CI: Confidence Interval; day_c: centred daily camp; σ^2 : residual variance; τ_{00} ID: Intercept variance; τ_{11} ID.day_c: Slope variance; ρ_{01} ID: Intercept-slope correlation; ICC: Intraclass Correlation Coefficient.

Model-based predicted HR values across relative camp days are shown in Figure 15. In the presence of an interaction between camp day and glucose, the temporal slope of nocturnal HR is

conditional on glucose values. For this reason, subject-specific slopes were not summarised for Model 2, and interpretation relied on fixed effects and model-based predictions.

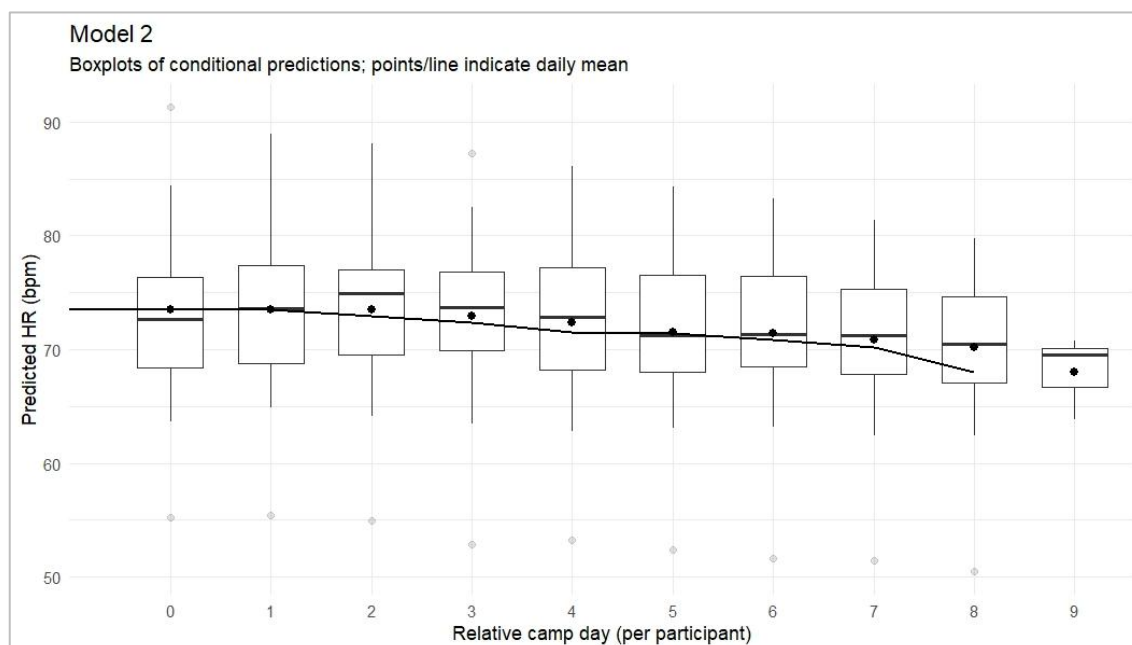


Figure 15. Model 2. Conditional predictions of nocturnal HR from the mixed-effects model with glucose across camp days.

7.3.3 Model 3 – Linear mixed-effects model with within–between decomposition of glucose

In Model 3, nocturnal HR was analysed using a linear mixed-effects model including centred camp day and a within–between decomposition of nocturnal glucose, comprising the within-subject nightly deviation from each participant’s mean glucose level and the between-subject mean nocturnal glucose across the camp (glu_mean10), together with their interactions with camp day. Random intercepts and random slopes for centred camp day were included at the participant level. The fixed-effect estimate for centred camp day was negative but did not reach statistical significance. Neither the within-subject nor the between-subject glucose components showed statistically significant associations with nocturnal HR. Similarly, the interactions between camp day and both glucose components were not statistically significant. Fixed-effects estimates and variance components are reported in Table 18. The random-effects structure showed variability across participants in both baseline nocturnal HR and temporal trajectories. Model-based conditional predictions of nocturnal HR across relative camp days are shown in Figure 16.

Table 18. Model 3: nocturnal_HR ~ day_c + glu_wp10 + glu_mean10 + day_c × glu_wp10 + day_c × glu_mean10 + (day_c | ID). Fixed effects and variance components.

Predictor	Estimate	SE	df	p	95% CI
Intercept	75.63	9.09	19.37	<0.001	57.74 – 93.51
day_c	–0.47	1.37	22.35	0.732	–2.24 – 3.19
glu_wp10	0.09	0.07	141.89	0.278	–0.07 – +0.24
glu_mean10	–0.22	0.55	19.27	0.693	–1.34 – +0.89
day_c × glu_wp10	–0.01	0.02	142.62	0.763	–0.07– 0.05
day_c × glu_mean10	–0.07	0.08	21.65	0.424	–0.24– 0.10
Random Effects					
σ^2	33.67				
$\tau_{00 \text{ ID}}$	54.87				
$\tau_{11 \text{ ID.day_c}}$	0.60				
$\rho_{01 \text{ ID}}$	–0.12				
ICC	0.64				
N _{ID}	21				
Observations	174				
Marginal R ² / Conditional R ²	0.036 / 0.651				

SE: standard error; df: degrees of freedom; CI: Confidence Interval; day_c: centred daily camp; σ^2 : residual variance; $\tau_{00 \text{ ID}}$: Intercept variance; $\tau_{11 \text{ ID.day_c}}$: Slope variance; $\rho_{01 \text{ ID}}$: Intercept-slope correlation; ICC: Intraclass Correlation Coefficient.

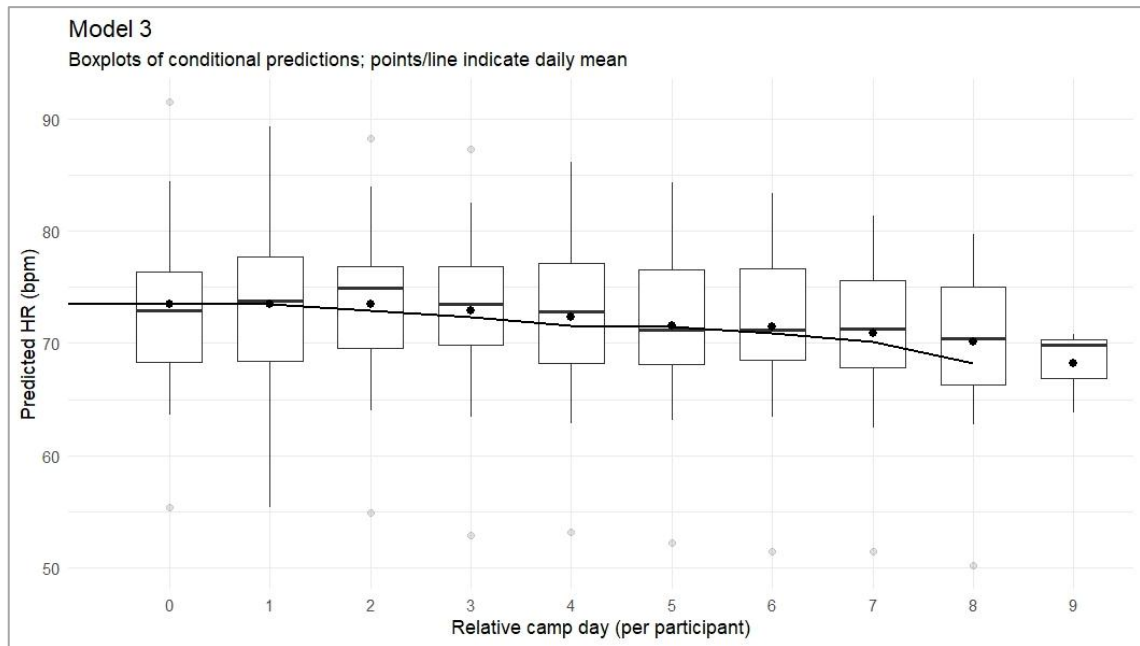


Figure 16. Model 3. Conditional predictions of nocturnal HR from the within–between model across camp days.

7.3.4 Model comparisons

The comparison between Model 1 and Model 2 did not indicate an improvement in model fit following the inclusion of nocturnal glucose ($\chi^2(2) = 1.71$, $p = 0.42$). Consistently, information criteria did not favour the extended model ($\Delta\text{AIC} = 2.28$; $\Delta\text{BIC} = 8.60$). The comparison between Model 2 and Model 3 showed no improvement in likelihood ($\chi^2(2) = 0.80$, $p = 0.67$), nor in AIC or BIC ($\Delta\text{AIC} = 3.20$; $\Delta\text{BIC} = 9.52$). Overall, the inclusion of nocturnal glucose, either as a simple covariate or decomposed into within–between components, did not provide any advantage over the time-only model.

7.4 Discussion

The present study aimed to evaluate whether nocturnal HR showed a trend throughout camp days, whether nocturnal HR was associated with nocturnal glucose levels, and lastly whether separating glucose into between-participant and within-participant components added information to the models. We found that nocturnal HR progressively decreased across camp days, whereas nocturnal glucose was not associated with nocturnal HR in the models examined in this study. The progressive decline in nocturnal HR suggests a process of physiological adaptation over the

course of the camp. In physiological terms, nocturnal reductions in HR are closely related to the concept of nocturnal HR dipping, defined as the normal decline in heart rate during sleep compared with daytime values. Preserved nocturnal dipping reflects intact circadian autonomic regulation and predominance of parasympathetic activity during sleep, whereas blunted or absent dipping has been associated with increased cardiovascular risk in adult populations¹⁴⁷. Evidence on nocturnal HR dipping in children and adolescents, however, remains limited and largely condition-specific, and no studies to date have examined nocturnal HR patterns in adolescents with T1D during diabetes summer camps. Within this framework, the observed progressive reduction in nocturnal HR across camp days may reflect an enhancement of nocturnal autonomic regulation rather than an acute response to isolated stimuli. From a cardiovascular perspective, reductions in resting and nocturnal HR are typical of training-induced adaptations, reflecting improved aerobic fitness, enhanced parasympathetic tone and reduced sympathetic activation^{143,145}. Diabetes summer camps provide structured opportunities for daily PA, combining planned exercise sessions with spontaneous outdoor activity, which can temporarily increase habitual movement levels in adolescents with T1D¹⁵⁸. PA is recommended for youth with T1D and improves both metabolic and psychological outcomes^{149,150}, although this population is typically less active and more sedentary than peers^{86,159}. Beyond PA, camp-based interventions may also influence emotional and psychosocial processes. Indeed, youth with T1D face a chronic disease burden that impacts metabolic, emotional and relational domains^{152,160}. Camps have been associated with improvements in knowledge, self-efficacy, anxiety, quality of life and psychological well-being¹⁵¹. Stress, anxiety and emotional arousal modulate autonomic balance and HR through sympathetic and parasympathetic pathways^{161,162}, and HRV is considered a sensitive marker of stress reactivity in youth¹⁵⁴. Peer support, shared experiences and daily routines may therefore have contributed to reduced stress load, facilitating autonomic recovery and strengthening the interpretation of nocturnal HR as an integrated physiological marker. The natural outdoor environment of the camp may have further supported psychophysiological recovery. The “green exercise” literature indicates that PA performed in natural environments provides additional benefits on mood, stress reduction and psychological well-being compared to

urban settings^{29,32}. Recent real-world studies also suggest effects on sleep and recovery. Although our design does not allow disentangling environmental from behavioural or psychosocial components, the combination of nature exposure, reduced artificial stressors and regular daily rhythms plausibly contributed to the observed decline in nocturnal HR. Regarding the second aim, nocturnal glucose did not show a significant association with nocturnal HR. This diverges from CGM-based studies reporting increased HR and altered HRV during nocturnal hypoglycemia^{163,164}. However, in our study glucose was measured once per night via fingerstick, potentially missing transient hypoglycemic episodes. Moreover, nocturnal hypoglycemia may have been less frequent due to close clinical supervision, structured meals and repeated glucose checks during the camp. Under these conditions, nocturnal HR likely reflected background autonomic tone and cumulative adaptation rather than acute glycemic fluctuations. Finally, decomposing glucose into between-participant and within-participant components did not improve model fit, suggesting that neither individual differences in average nocturnal glucose nor nightly deviations from personal means exerted a detectable influence on nocturnal HR. In this model, the inclusion of interactions between camp day and glucose components implies that temporal slopes are conditional on glucose values; accordingly, the interpretation focused on fixed-effect estimates, variance components and model-based predictions rather than on individual slope directions. From a clinical perspective, these findings are consistent with the idea that autonomic adaptation during structured camps may be influenced more by behavioral, psychological and environmental factors than by modest variations in nocturnal glycemia.

From a methodological point of view, the study confirms the feasibility of using wrist-worn wearables based on PPG to monitor nocturnal HR in adolescents with T1D. PPG enables continuous, non-invasive HR monitoring with low participant burden^{156,157}. Integrating wearable-based autonomic indicators alongside metabolic, behavioral and psychosocial measures may enrich the evaluation of diabetes summer camps and inform interventions that target not only glycemic control and education, but also recovery, stress regulation and cardiovascular health.

7.5 Limitations

This study presents some limitations. First, the sample size was small and included both male and female participants, but not enough to explore potential sex differences. Second, nocturnal glucose was assessed using a single capillary fingerstick rather than CGM, which may have limited the characterization of glycemic fluctuations and their relationship with nocturnal HR. Third, HR was the only physiological parameter collected. The absence of HRV and sleep stages parameters restricted the interpretation of autonomic mechanisms underlying the observed trend. Technical aspects should also be considered, as wrist-worn PPG devices are susceptible to motion artefacts, and daytime data coverage was incomplete, preventing integration of daytime activity and HR. Finally, the study was conducted in a single diabetes summer camp with specific organizational features, which may limit generalizability. Larger and controlled studies with more comprehensive monitoring are needed to confirm and extend these findings.

7.6 Conclusions

In conclusion, participation in a structured diabetes summer camp was associated with a progressive reduction in nocturnal HR in adolescents with T1D, consistent with a process of autonomic recovery. This trend likely reflects the combined influence of multiple components of the camp experience, including increased PA, improved emotional well-being, peer support, exposure to a natural environment and structured diabetes management. Nocturnal glucose was not significantly related to HR, suggesting that cumulative physiological adaptation may be more relevant in this context than acute glycemic fluctuations. These findings highlight the potential value of wearable-based physiological monitoring to capture integrated responses to complex behavioural and psychosocial interventions such as diabetes camps and motivate future studies with more comprehensive and controlled designs.

8. CONCLUSIONS AND PRACTICAL IMPLICATIONS

8. Conclusions and Practical Implications

8.1 General Conclusions

In the present doctoral project, the evidence shows that accelerometry, and specifically actigraphy, are versatile, scalable and methodologically strong tools to evaluate 24-hour behaviors and their integration with clinical, physiological and metabolic parameters. The experimental design adopted, characterized by a progression from ecological to rehabilitative and pediatric clinical contexts, highlighted how wearable technologies can contribute both to the understanding of behavioral determinants of non-communicable diseases (NCDs) and to the development of predictive models and *digital health* applications relevant to personalized prevention and management. Overall, the results show that the continuous observation of motor behavior, sedentary time, sleep and heart rate, integrated with clinical and metabolic parameters, allows for a more comprehensive understanding of health dynamics compared to traditional measurements in clinical environments. This approach supports a precision-prevention perspective, in which individuals are monitored in their own real-world and free-living conditions, thus overcoming the gap between clinical and behavioral ecosystems.

Finally, the combined use of wearable sensors and advanced statistical models supports the transition to *digital health* ecosystems that provide personalized and timely information, potentially relevant to health education, rehabilitation, clinical follow-up and telemonitoring. These results contribute to enriching the discussion on *digital health* and strengthen its value at both scientific and applied levels, confirming the need to integrate behavioral and physiological dimensions in the prevention of NCDs and in the promotion of healthy lifestyles.

8.2 Specific Conclusions

In the first study related to the accelerometric analysis of *plogging*, the application of accelerometry in an ecological context allowed us to characterize plogging as an intermittent physical activity (PA) located between light and moderate intensity, with an increase in energy expenditure as the overload of collected waste increased. These findings suggest that plogging

may be integrated into PA promotion and environmental education programs in young populations. In the second study, which focused on multimodal programs for urinary incontinence (UI), the integration of accelerometry with clinical measurements and questionnaires showed a clinically relevant improvement in UI symptoms, despite no significant changes in PA levels. This indicates that rehabilitative effects may emerge even without an increase in daily movement volume. The use of wearable devices represents an added value in the monitoring of conservative rehabilitation pathways. In the first of the three central studies, which focused on integrated monitoring during a pediatric summer camp for youth with type 1 diabetes (T1D), the continuous monitoring of PA, sedentary behavior and sleep before and during camp participation showed a significant increase in PA and a decrease in sedentary behavior, associated with improvements in sleep continuity. This suggests that structured educational interventions and high movement density may improve behavioral determinants in pediatric populations with chronic disease. In the fourth study, which focused on PA and glycemic dynamics, the combined analysis of steps, carbohydrate intake, insulin adjustments and blood glucose levels showed that, although steps were not a linear predictor of glycemia, they improved forecasting performance when included in the model. This confirms the relevance of the behavioral component in the understanding of metabolic dynamics during developmental age. In the last study, which focused on nocturnal heart rate (HR) adaptation, the monitoring of nocturnal HR using photoplethysmography (PPG) sensors showed a progressive decrease in HR across camp days, indicative of an improvement in autonomic recovery. This adaptation appeared to be substantially independent of acute glycemic fluctuations, suggesting a physiological mechanism linked to greater exposure to PA.

8.3. Practical Implications

The results of this project show several practical applications in the educational, rehabilitative and clinical fields, and contribute to the evolution of *digital health* solutions oriented towards the prevention and monitoring of NCDs. First, the use of accelerometric tools in real-world contexts suggests that activities such as plogging could be integrated into school and extracurricular programs aimed at promoting physical activity and environmental awareness in younger

generations. This approach offers an accessible and replicable strategy, with potential positive effects on daily movement. In the rehabilitative field, the combined use of actigraphy and clinical measurements showed that symptom improvement may occur even without increases in habitual PA. This indicates that wearable monitoring can represent a useful support tool in conservative programs for urinary incontinence, providing additional information relevant to personalized interventions. In the clinical pediatric field, integrated monitoring during the camp for children and adolescents with type 1 diabetes highlighted the role of educational experiences with a high density of PA in the modulation of behavioral and sleep-related determinants. These findings support the inclusion of motor and educational camps as complementary activities to traditional clinical programs, with possible effects on the daily management of the disease. The modelling of short-term glycemic dynamics suggests that PA may improve outcomes in forecasting models. This perspective shows potential applications in the field of telemedicine, decision-support systems and personalized management of chronic disease during developmental age. Finally, the analysis of nocturnal heart rate shows that actigraphy can provide useful information to understand autonomic recovery processes, with possible future applications in physiological monitoring programs and in the evaluation of PA load in youth with NCDs. In general, the practical applications derived from this project confirm the value of accelerometry, and consequently of actigraphy, as useful tools for the prevention and management of chronic diseases and support their integration into educational, rehabilitative and clinical programs oriented towards continuous monitoring and personalized intervention.

9. LIMITATIONS AND FUTURE PERSPECTIVES

9. Limitations and Future Perspectives

9.1 Limitations

This doctoral project presents also some methodological, technological and contextual limitations that should be considered when interpreting the results.

First, the five studies relied on relatively small samples, which may limit the generalizability of the findings and restrict the possibility of conducting stratified analyses by sex, age or clinical characteristics. Moreover, the observation periods were short and, in some cases, limited to specific events (e.g., pediatric summer camps), preventing the assessment of long-term behavioral and physiological adaptations in free-living conditions.

A second limitation concerns the technological dimension. Although accelerometry provide continuous monitoring of movement, sedentary behavior and sleep, they lack certain physiological signals that could enhance interpretation, such as heart rate variability (HRV), continuous glucose monitoring (CGM) or circadian markers. In addition, wearable signal quality, particularly in photoplethysmography (PPG), may be affected by motion artifacts or compliance issues, reducing data completeness.

A third set of limitations relates to study design. Some studies were cross-sectional or non-controlled, limiting causal inferences and reducing the capacity to isolate the role of PA from contextual factors. Dietary intake, insulin adjustments and other lifestyle-related variables were not continuously monitored, restricting the mechanistic interpretation of metabolic responses. In the modelling studies, the use of a limited set of PA variables and the lack of external validation constrained the generalizability of the forecasting model and reduced its potential translational value. External validation in independent cohorts would be necessary to assess robustness across different populations and settings.

9.2 Future perspectives

Future research should consider the integration of multimodal physiological and behavioral signals, including CGM, HRV and chronobiological markers, in order to better characterize the interplay between behavior, metabolism and autonomic regulation. The adoption of longer and longitudinal observation periods in free-living conditions may allow the evaluation of long-term adaptations and inter-individual variability in youth with non-communicable diseases (NCDs). From a methodological perspective, including other PA features, refining analytical pipelines and validating forecasting models in external cohorts could strengthen the role of actigraphy in *digital health* applications. The inclusion of ecologically valid interventions and structured behavioral components may contribute to clarifying the effects of PA on metabolic and autonomic outcomes. Finally, the integration of wearable monitoring within educational, rehabilitative and clinical pathways may support the development of telemonitoring protocols and decision-support tools aimed at personalized management of NCDs during developmental age. However, further research is needed to determine feasibility, clinical utility and cost-effectiveness in real-world settings.

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11. APPENDICES

Appendix A – Pelvic Floor Distress Inventory 20 Items (Pfdi-20)

Pelvic Floor Disability Index (PFDI-20)

Istruzioni: per favore risponda a tutte le domande del seguente questionario. Queste domande valuteranno se lei ha determinati sintomi intestinali, vescicali o pelvici e, in tal caso, **quanto la infastidiscono**. Risponda cercando il numero più appropriato. Mentre risponde a queste domande, consideri i sintomi negli ultimi 3 mesi. Il PFDI-20 ha 20 domande e 3 domini di sintomi. Tutte le domande utilizzano la seguente scala da 0 a 4.

Scala di sintomi:

- 0 = non presente**
- 1 = per nulla**
- 2 = poco**
- 3 = moderatamente**
- 4 = tanto**

Pelvic Organ Prolapse Distress Inventory 6 (POPDI-6)

Le capita di...	No	Yes			
1 - Percepire regolarmente una pressione nel basso addome?	0	1	2	3	4
2 - Percepire regolarmente pesantezza o rigidità nell'area pelvica?	0	1	2	3	4
3 - Percepire regolarmente una protuberanza o qualcosa che fuoriesce dalla zona vaginale alla vista o al tatto?	0	1	2	3	4
4 - Dover spingere in vagina o nella zona intorno al retto per poter defecare?	0	1	2	3	4
5 - Percepire regolarmente la sensazione di incompleto svuotamento vescicale?	0	1	2	3	4
6 - Dover spingere una protuberanza nell'area vaginale per poter iniziare o completare lo svuotamento vescicale?	0	1	2	3	4

ColoRectal-Anal Distress Inventory 8 (CRAD-8)

Le capita di...	No	Yes			
7 - Percepire la necessità di dover spingere troppo intensamente per defecare?	0	1	2	3	4
8 - Percepire di non aver completamente svuotato l'intestino al termine della defecazione?	0	1	2	3	4
9 - Avere regolarmente episodi di incontinenza anale se le feci sono ben formate?	0	1	2	3	4

10 - Avere regolarmente episodi di incontinenza anale se le feci sono liquide?	0	1	2	3	4
11 - Avere regolarmente episodi di incontinenza anale ai gas?	0	1	2	3	4
12 - Avere regolarmente dolore al passaggio delle feci?	0	1	2	3	4
13 - Percepire una forte sensazione di urgenza e di dover correre in bagno a defecare?	0	1	2	3	4
14 - Assistere alla protrusione di una parte dell'intestino attraverso il retto durante o dopo la defecazione?	0	1	2	3	4

Urinary Distress Inventory 6 (UDI-6)

Le capita di...	No	Yes			
15 - Percepire regolarmente una esagerata frequenza minzionale?	0	1	2	3	4
16 - Percepire regolarmente una fuga urinaria associata a sensazione di urgenza, che è il desiderio improrogabile di andare al bagno?	0	1	2	3	4
17 - Percepire regolarmente una fuga urinaria associata a tosse, stranuti o risate?	0	1	2	3	4
18 - Percepire regolarmente piccole fughe di urina, ovvero gocce?	0	1	2	3	4
19 - Percepire regolarmente una difficoltà a svuotare la vescica?	0	1	2	3	4
20 - Percepire regolarmente dolore o discomfort al basso addome o in regione genitale?	0	1	2	3	4

Calcolo dello score del PFDI-20

- **Punteggio del dominio:** Calcolare la media tra i punteggi ottenuti per gli item del dominio (valori possibili compresi tra 0 e 4) e moltiplicare per 25 per ottenere il punteggio del dominio (range tra 0 e 100). In caso di risposte mancanti considerare la media derivante dalle restanti risposte.
- **Punteggio totale del PFDI-20:** Sommare i punteggi dei 3 domini per ottenere il punteggio totale (range tra 0 e 300)

Appendix B – Adolescent Sedentary Activity Questionnaire (Asaq) Greek Version

Ερωτηματολόγιο Καθιστικής Συμπεριφοράς Εφήβων (Ε.Κ.Σ.Ε)

1.Μια τυπική ημέρα της εβδομάδας που έχεις σχολείο, συνήθως πόσες ώρες/λεπτά διαθέτεις: (Σκέψου τι κάνεις από την ώρα που τελειώνει το σχολείο και επιστρέφεις στο σπίτι μέχρι την ώρα που πέφτεις για ύπνο. ΠΡΟΣΟΧΗ ο διαθέσιμος ελεύθερος χρόνος σου δεν μπορεί να υπερβαίνει τις 12 ώρες ημερησίως).	Αριθμός ωρών και λεπτών (σχολική ημέρα)	
	ώρες	λεπτά
[1] Παρακολουθώντας τηλεόραση/video/DVD;		
[2] Παίζοντας ηλεκτρονικά σε κονσόλες (παράδειγμα Wii, Xbox 360, PS3, Nintendo);		
[3] Χρησιμοποιώντας τον υπολογιστή για διασκέδαση (παιχνίδια, σερφάροντας στο διαδίκτυο) ή σε κοινωνικά δίκτυα (π.χ Facebook, twitter);		
[4] Μελετώντας τα μαθήματα σχολείου ή φροντιστηρίου (περιλαμβάνονται και οι εργασίες με τη χρήση του υπολογιστή);		
[5] Σε ωδεία, φροντιστήρια ξένων γλωσσών, ή άλλα φροντιστήρια μαθημάτων;		
[6] Διαβάζοντας βιβλία, περιοδικά, εφημερίδες ή ακούγοντας μουσική;		
[7] Καθισμένος, κάνοντας χόμπι ή κατασκευές ή κάνοντας πρακτική σε κάποιο μουσικό όργανο (όχι αθλητισμό).		
[8] Συνομιλώντας στο τηλέφωνο (ή στέλνοντας μηνύματα) ενώ κάθεσαι;		
[9] Για μετακίνηση με αυτοκίνητο ή άλλο μηχανοκίνητο μέσο (για το σχολείο, φροντιστήρια, άλλες ασχολίες κλπ.)		

2.Μια τυπική ημέρα του ΣΑΒΒΑΤΟΚΥΡΙΑΚΟΥ, συνήθως πόσες ώρες/λεπτά διαθέτεις:	Σάββατο		Κυριακή	
	ώρες	λεπτά	ώρες	λεπτά
[1] Παρακολουθώντας τηλεόραση/video/DVD;				
[2] Παίζοντας ηλεκτρονικά σε κονσόλες (παράδειγμα Wii, Xbox 360, PS4, Xbox,Nintendo);				
[3] Χρησιμοποιώντας τον υπολογιστή για διασκέδαση (παιχνίδια, σερφάροντας στο διαδίκτυο) ή σε κοινωνικά δίκτυα (π.χ Facebook, twitter);				
[4] Μελετώντας τα μαθήματα σχολείου ή φροντιστηρίου (περιλαμβάνονται και οι εργασίες με τη χρήση του υπολογιστή);				
[5] Σε ωδεία, φροντιστήρια ξένων γλωσσών, ή άλλα φροντιστήρια μαθημάτων;				
[6] Διαβάζοντας βιβλία, περιοδικά, εφημερίδες ή ακούγοντας μουσική;				
[7] Καθισμένος, κάνοντας χόμπι ή κατασκευές ή κάνοντας πρακτική σε κάποιο μουσικό όργανο (όχι αθλητισμό).				
[8] Συνομιλώντας στο τηλέφωνο (ή στέλνοντας μηνύματα) ενώ κάθεσαι;				
[9] Για μετακίνηση με αυτοκίνητο ή άλλο μηχανοκίνητο μέσο (για το σχολείο, φροντιστήρια, άλλες ασχολίες κλπ.)				

Appendix C – Physical Activity Questionnaire For Older Children (Paq – C) Greek Version

Ερωτηματολόγιο Φυσικής Δραστηριότητας για παιδιά 8-14 ετών

Όνομα: Ηλικία:
 Φύλο: Α..... Κ.....@..... Τάξη:
 Δάσκαλος:

Προσπαθούμε να αξιολογήσουμε το επίπεδο της φυσικής σας δραστηριότητας τις τελευταίες 7 ημέρες (την τελευταία εβδομάδα). Ο έλεγχος αυτός περιλαμβάνει αθλήματα ή χορό που προκαλούν εφίδρωση ή κουράζουν τα πόδια σας, καθώς και παιχνίδια που σας κάνουν να ανασαίνετε βαριά, όπως για παράδειγμα κυνηγητό, πηδηματάκια/σχοινάκι, τρέξιμο, σκαρφάλωμα κ.α.

Θυμηθείτε:

1. Δεν υπάρχει σωστή ή λάθος απάντηση – αυτό το ερωτηματολόγιο δεν είναι τεστ.
2. Παρακαλώ, απαντήστε όλες τις ερωτήσεις με ειλικρίνεια και ακρίβεια – αυτό είναι πολύ σημαντικό.

1. Άσκηση στον ελεύθερο σας χρόνο. Έχεις κάνει/δοκιμάσει κάποια από τις παρακάτω δραστηριότητες τις τελευταίες 7 ημέρες (την τελευταία εβδομάδα); Αν ναι, πόσες φορές; (Παρακαλώ σημειώστε μία απάντηση ανά γραμμή).

	Όχι	1-2	3-4	5-6	7 φορές ή περισσότερες
Πηδηματάκια / σχοινάκι	☐	☐	☐	☐	☐
Κωπηλασία / Κανό	☐	☐	☐	☐	☐
Πατινάζ με rollers	☐	☐	☐	☐	☐
Κυνηγητό	☐	☐	☐	☐	☐
Περπάτημα (για άσκηση)	☐	☐	☐	☐	☐
Ποδηλασία.....	☐	☐	☐	☐	☐
Τρέξιμο	☐	☐	☐	☐	☐
Αεροβική	☐	☐	☐	☐	☐
Κολύμβηση	☐	☐	☐	☐	☐
Μπέιζμπολ / σόφτμπολ	☐	☐	☐	☐	☐
Χορός	☐	☐	☐	☐	☐
Ποδόσφαιρο / Ραγκμπι	☐	☐	☐	☐	☐
Μπάντμιντον / Αντιπότεριση	☐	☐	☐	☐	☐
Σκέιτμπορντ	☐	☐	☐	☐	☐
Ποδόσφαιρο	☐	☐	☐	☐	☐
Χόκεϊ στην άσφαλτο / στο έδαφος	☐	☐	☐	☐	☐
Βόλλεϋ	☐	☐	☐	☐	☐
Χόκεϊ σε τερέν	☐	☐	☐	☐	☐
Μπάσκετ	☐	☐	☐	☐	☐
Πατινάζ σε πάγο	☐	☐	☐	☐	☐
Σκι αντοχής	☐	☐	☐	☐	☐
Σχοινάκι	☐	☐	☐	☐	☐
ΑΛΛΟ:					
.....	☐	☐	☐	☐	☐
.....	☐	☐	☐	☐	☐

Reference: Kowalski, K., Crocker, P., & Dornen, R. (2004). The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A) Manual. College of Kinesiology, University of Saskatchewan.

2. Τις τελευταίες 7 ημέρες, κατά τη διάρκεια του μαθήματος της Φυσικής Αγωγής, πόσο συχνά ήσουν πολύ ενεργός/ δραστήριος (παιζοντας έντονα, τρέχοντας, πετώντας, πετώντας (τη μπάλα). (Επίλεξε μόνο μία απάντηση)

Δε συμμετέχω στο μάθημα της Φυσικής Αγωγής ☐
 Σχεδόν Ποτέ..... ☐
 Κάποιες φορές..... ☐
 Συχνά..... ☐
 Πάντα..... ☐

3. Τις τελευταίες 7 ημέρες, τι έκανες την περισσότερη ώρα του διαλείμματος; (Επίλεξε μόνο μία απάντηση)

Καθόμουν (μιλούσα, διάβαζα, έκανα τις εργασίες μου) ☐
 Στεκόμουν ή περπατούσα ☐
 Έτρεχα ή έπαιξα για λίγο ☐
 Έτρεχα ή έπαιξα για αρκετή ώρα ☐
 Έτρεχα και έπαιξα την περισσότερη ώρα ☐

4. Τις τελευταίες 7 ημέρες, τι έκανες την ώρα του μεσημεριανού φαγητού (έκτος από το να τρως το γεύμα σου); (Επίλεξε μόνο μία απάντηση)

Καθόμουν (μιλούσα, διάβαζα, έκανα τις εργασίες μου) ☐
 Στεκόμουν ή περπατούσα ☐
 Έτρεχα ή έπαιξα για λίγο ☐
 Έτρεχα ή έπαιξα για αρκετή ώρα ☐
 Έτρεχα και έπαιξα την περισσότερη ώρα ☐

5. Τις τελευταίες 7 ημέρες, πόσες ημέρες αμέσως μετά το σχολείο, έκανες κάποιο άθλημα, χορό ή έπαιξες κάποιο παιχνίδι στο οποίο ήσουν πολύ ενεργός/δραστήριος; (Επίλεξε μόνο μία απάντηση)

Καμία ☐
 1 φορά την προηγούμενη εβδομάδα ☐
 2 ή 3 φορές την προηγούμενη εβδομάδα ☐
 4 φορές την προηγούμενη εβδομάδα ☐
 5 φορές την προηγούμενη εβδομάδα ☐

6. Τις τελευταίες 7 ημέρες, πόσα απογεύματα/βράδια έκανες κάποιο άθλημα, χορό ή έπαιξες παιχνίδια στα οποία ήσουν πολύ ενεργός/δραστήριος; (Επίλεξε μόνο μία απάντηση)

Καμία ☐
 1 φορά την προηγούμενη εβδομάδα ☐
 2 ή 3 φορές την προηγούμενη εβδομάδα ☐
 4 ή 5 φορές την προηγούμενη εβδομάδα ☐
 6 ή 7 φορές την προηγούμενη εβδομάδα ☐

Reference: Kowalski, K., Crocker, P., & Donen, R. (2004). The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A) Manual. College of Kinesiology, University of Saskatchewan.

7. Το τελευταίο σαββατοκύριακο, πόσες φορές έκανες κάποιο άθλημα, χορό ή έπαιξες παιχνίδια στα οποία ήσουν πολύ ενεργός/δραστήριος; (Επίλεξε μόνο μία απάντηση)

- Καμία ☐
 1 φορά ☐
 2-3 φορές ☐
 4-5 φορές ☐
 6 ή περισσότερες φορές ☐

8. Ποια από τις παρακάτω φράσεις, σε περιγράφει καλύτερα για τις τελευταίες 7 ημέρες; Διάβασε όλες τις φράσεις πριν αποφασίσεις ποια είναι αυτή που σε περιγράφει.

- A. Όλο ή τον περισσότερο ελεύθερο χρόνο μου έκανα πράγματα που απαιτούσαν λίγη σωματική προσπάθεια ☐
 B. Κάποιες φορές (1-2 φορές την προηγούμενη εβδομάδα) έκανα αθλητικές δραστηριότητες (πχ έκανα αθλήματα, τρέξιμο, κολύμβηση, ποδήλατο, αεροβική) ☐
 C. Συχνά (3-4 φορές την προηγούμενη εβδομάδα) έκανα αθλητικές δραστηριότητες στον ελεύθερο μου χρόνο ☐
 D. Αρκετά συχνά (5-6 φορές την προηγούμενη εβδομάδα) έκανα αθλητικές δραστηριότητες στον ελεύθερο μου χρόνο ☐
 E. Πολύ συχνά (7 ή περισσότερες φορές την προηγούμενη εβδομάδα) έκανα αθλητικές δραστηριότητες στον ελεύθερο χρόνο μου ☐

9. Σημείωσε πόσο συχνά έκανες κάποια αθλητική δραστηριότητα (για παράδειγμα, κάποιο άθλημα, παιχνίδια, χορό ή οποιαδήποτε άλλη δραστηριότητα) για κάθε ημέρα της προηγούμενης εβδομάδας.

	Καθόλου	Πολύ Λίγο	Μέτρια	Συχνά	Πολύ Συχνά
Δευτέρα	☐	☐	☐	☐	☐
Τρίτη	☐	☐	☐	☐	☐
Τετάρτη	☐	☐	☐	☐	☐
Πέμπτη	☐	☐	☐	☐	☐
Παρασκευή	☐	☐	☐	☐	☐
Σάββατο	☐	☐	☐	☐	☐
Κυριακή	☐	☐	☐	☐	☐

10. Ήσουν ασθενής την προηγούμενη εβδομάδα ή συνέβη κάτι που σε εμπόδιζε από το να κάνεις τις συνηθισμένες σου αθλητικές δραστηριότητες; (Επίλεξε ένα)

- Ναι ☐
 Όχι ☐

Αν ναι, τι ήταν αυτό που σε εμπόδιζε;

Reference: Kowalski, K., Crocker, P., & Donen, R. (2004). The Physical Activity Questionnaire for Older Children (PAQ-C) and Adolescents (PAQ-A) Manual. College of Kinesiology, University of Saskatchewan.

Appendix D – Measurement Log Of The Fitness Assessments Performed Prior To Participation In The Diabetes Summer Camp

TEST LOG

Name and Surname _____ ID _____
 Date _____

EYE-HAND SPEED AND COORDINATION - *TAPPING TEST*

Record the time spent to complete 50 alternately touches tapping the circles. The final score is the fastest time spent.

Attempt 1		Attempt 2	
Time:		Time:	

SCORE: _____

TRUNK EXTENSOR STRENGTH AND FLEXIBILITY – *TRUNK LIFT TEST*

Record the best result corresponding to the highest cm reached lifting the upper body measuring the distance from the mat and the chin.

Attempt 1		Attempt 2	
Height:		Height:	

SCORE: _____

UPPER BODY STRENGTH– *HANDGRIP*

Read the result on the dynamometer during the 3-5 seconds squeezing and alternate the hands each attempt. Record the best result between the attempts performed.

	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5
Right hand (kg)					
Left hand (kg)					

SCORE: _____

Appendix E – Informed Consent For Participation In The Multimodal Intervention Study On Urinary Incontinence

CONSENSO INFORMATO – DICHIARAZIONE DI CONSENSO

Titolo del progetto: Women Work for Women Healthcare

Nome e Cognome del Medico/Sperimentatore responsabile:

Numero del soggetto: _____

- 1) Dichiaro di aver letto e compreso le informazioni di cui sopra, di aver avuto l'opportunità di porre domande in merito e prendo atto che mi sarà consegnata una copia del Foglio Informativo – Consenso Informato firmato e datato.
- 2) Ho compreso che il consenso alla raccolta dei miei dati è volontario e che sono libero/a di ritirarlo in qualsiasi momento, senza fornire ragioni e senza che ciò abbia conseguenza sull'assistenza medica o sui miei diritti legali.
- 3) Accetto di partecipare a questo studio sapendo che dal medesimo non deriverà alcun beneficio diretto per me e che firmando il presente modulo non rinuncio ai diritti legali applicabili.
- 4) Per quanto riguarda i miei diritti di cui al D.Lgs n.196/2003 sulla protezione dei dati personali, sottoscriverò l'apposita informativa e il modulo di manifestazione del consenso al trattamento dei dati personali.

Firma del soggetto	Nome e Cognome del soggetto (in stampatello)	Data
Firma del medico proponente	Nome e Cognome del medico (in stampatello)	Data

Autorizzazione al trattamento dei dati per ALTRI studi di ricerca clinica

Gentile paziente, vorremmo informarla che i dati ricavati dalle sue immagini potrebbero essere utilizzati in forma del tutto anonima per ulteriori scopi di ricerca clinica, prevalentemente su base di analisi statistica, volti al miglioramento della prevenzione e terapia di molte condizioni patologiche. I suoi dati potranno essere utilizzati per altri studi previa accettazione del Comitato Etico di riferimento.

☐ Autorizzo - ☐ Non autorizzo

Firma del soggetto (in stampatello)	Nome e Cognome del soggetto	Data
Firma del medico proponente (in stampatello)	Nome e Cognome del medico	Data

Appendix F – Informed Consent For Participation In The Diabetes Summer Camp Project

INFORMATION AND CONSENT FORM TO PARTICIPATION AND DATA PROCESSING FOR MINORS

DESCRIPTION AND AIM OF THE RESEARCH

With this form, we kindly ask you to provide your informed consent for the participation of your child in the project "Assessment of the level of physical activity and adaptation to insulin therapy in children and adolescents with type 1 diabetes during the summer period and camping. Correlation with anthropometric parameters, glycemic control, diet, and quality of life of the children", coordinated by Prof. Kiriaki Tsirokidou. The purpose of this project is to investigate how levels of physical activity and sedentary behaviors influence the management of type 1 diabetes in youth and to develop personalized recommendations to optimize insulin therapy. This will be achieved through the administration of questionnaires, physical tests, and the use of an electronic device to record movements.

METHODOLOGY OF THE RESEARCH

The research will take place in three phases, before, during and after the summer camp. During the research we'll ask to the minor 1) to answer to the questions compiling two questionnaires; 2) to wear an electronic device, the FitBit, to record the daily movements; 3) to perform three physical tests.

In details we'll use the following tools:

Questionnaires

- o The Greek version of the *Adolescents Sedentary Activity Questionnaire (ASAQ)* Hardy et al. (2007) which assesses the time spent in a comprehensive range of sedentary activities in five domains (recreational screen-time, educational, cultural, social, and transportation), among school-aged young people (11-15 y), outside of school hours recall the last 7 week. The participants reported the time spent in each sedentary behavior in hours and minutes during a typical weekday and weekend day. This instrument is composed into two parts, one based on the sedentary behaviors of the last weekdays, and one based on sedentary behaviors of the last weekend. The final score is given by the sum of the minutes spent in each sedentary activity in the weekdays and in the weekend and the total is obtained by the sum of the minutes scored in the weekday and the weekend.
- o The second is the Greek version of the *Physical Activity Questionnaire (PAQ-C)* Crocker et al. (1997), which is a self-administered instrument with a 7-day recall period. It was specifically designed to evaluate overall levels of physical activity among children aged approximately 8 to 14 years old. The final score is derived from nine items, with each item being scored on a 5-point scale, from 1 which means low physical activity level (PAL), to 5 which means high PAL.

Electronical device

- o *Fitbit HR Inspire* is a commercial electronic device which provides information about the physical activity and sedentary of the children and adolescents thanks to some characteristics of the product. In details provides information about Heart Rate, Steps, Distance, Calories Burned, Active Minutes, Sleep Tracking, Exercise Modes. To assure the correct recording of every activity performed by the participants, they'll must wear the device on their non-dominant wrist day and night.

Physical tests

- o *Handgrip test* → Also known as the handgrip strength test, is a simple assessment used to measure the strength of a person's hand and forearm muscles. It involves squeezing a handgrip dynamometer with maximum force using one hand, and the reading on the dynamometer indicates the amount of force exerted in kilograms or pounds.
- o *Tapping test* → This test measures eye-hand speed and coordination. Conducted at a table, it involves two sets of 50 alternating touches with the dominant hand on two yellow circles placed at opposite sides of a blue

rectangle, with the non-dominant hand positioned over the rectangle, allowing the dominant hand to pass over it.

- o *Trunk lift test* → This test measures trunk extensor strength and flexibility. The subject lies face-down on a mat with toes pointed back and hands placed behind the neck. A marker is placed on the mat in line with the eyes to help maintain head alignment during the movement. When ready, the subject slowly and controlledly lifts their upper body off the mat to a maximum he can keeping the head in line with the spine. The position is held long enough to measure the distance from the floor to the chin. After the measurement, the subject returns to the starting position. Two trials are allowed, and the best score is recorded. The trunk lift test requires two operators or a bed with a strap to tie the feet.

LOCATION AND DURATION OF THE RESEARCH

The research will be conducted at the Pediatric Endocrinology Unit of Ippokratio General Hospital in Thessaloniki for the first and third phase of the research and will last a total of 20 minutes (first meeting) and 30 minutes (second meeting). While the second phase, it will be conducted at the YMCA Summer Camp in Chalkidiki and will last 10 days.

REQUEST FOR PHONE NUMBER AND EMAIL TO SEND QUESTIONNAIRE LINK AND VALIDATE ACCOUNT

To facilitate sending the questionnaire link for your child to complete, and for the account creation, we kindly ask you to provide us with one of your phone numbers. This number will only be used for sending the questionnaire link and validating the account and will not be shared with third parties.

Phone Number: _____ Email: _____

CONSENT TO PARTICIPATION AND DATA PROCESSING

I, the undersigned: FATHER/MOTHER/TUTOR (SURNAME AND NAME IN CAPITAL LETTERS) _____

DECLARE that I'm the parent of the minor aware of the responsibilities provided for false attestations and declarations, under my personal responsibility (SURNAME AND NAME IN CAPITAL LETTERS) _____ and freely consent to their participation in the study titled "Assessment of the level of physical activity and adaptation to insulin therapy in children and adolescents with type 1 diabetes during the summer period and camping. Correlation with anthropometric parameters, glycemic control, diet, and quality of life of the children."

We, the undersigned, declare:

1. That I'm aware that the study complies with current laws D. Lgs 196/2003 and EU GDPR 679/2016 on data protection and consent to the processing and communication of personal data, within the limits, for the purposes, and for the duration specified by current laws (D. Lgs 196/2003 and EU GDPR 679/2016). The research supervisor commits to fulfilling the obligations set by current regulations in terms of collecting, processing, and storing sensitive data.
2. That I'm aware we can withdraw the minor from the study at any time, without providing explanations, without any penalty, and ensuring the non-use of the data.
3. That I'm aware that the data will be collected anonymously and associated with a code that allows only the participant to access their data.
4. That I'm aware that our data will be used exclusively for scientific and statistical purposes while maintaining confidentiality rules.
5. That I know, if desired, we can obtain the results in the form of aggregated data.
6. That I know a copy of this form will be provided to us by the researcher.

I, the undersigned (SURNAME AND NAME IN CAPITAL LETTERS) Father/Mother/Tutor _____ having read this form, express the consent to the participation and processing of our personal data and those of the minor.

Date _____

Legible signature _____

Article

Effects of a Multimodal Training Program for the Management of Urinary Incontinence and Physical Activity Levels on Symptom Perception and Urine Loss

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Abstract

Background: Urinary incontinence (UI) is common in women and negatively affects quality of life. Although pelvic floor muscle training (PFMT) is effective, most studies have focused on isolated muscle contractions. Less is known about multimodal programs integrating posture, breathing, and intra-abdominal pressure management. This study examined how urinary loss (UL) and moderate physical activity (MPA), measured objectively, relate to perceived pelvic floor disorders after a five-week multimodal intervention. **Methods:** Twenty women (40–70 years) with UI participated in three weekly 60 min sessions for five weeks. Outcomes were assessed before and after the intervention: UL using the pad test, physical activity with a wrist-worn accelerometer, and pelvic floor disorders with the Pelvic Floor Distress Inventory (PFDI-20). Paired *t*-tests or Wilcoxon tests and regression models were used to analyze changes and associations between variables. **Results:** UL significantly decreased after treatment ($p < 0.001$) as did total PFDI-20 ($p = 0.007$). Before treatment, PFDI-20 was mainly predicted by MPA ($\beta = -0.537$, $p = 0.013$). After treatment, UL became the strongest predictor of PFDI-20 ($\beta = 0.587$, $p = 0.008$) while Δ analyses confirmed that changes in both UL ($\beta = 0.444$, $p = 0.026$) and MPA ($\beta = -0.461$, $p = 0.021$) predicted improvements in perceived pelvic floor disorders. **Conclusions:** A five-week multimodal program reduced UL and improved perceived pelvic floor disorders. After treatment, symptoms were more strongly related to UL than to MPA. This study suggests that a multimodal exercise approach may represent a feasible and potentially effective option for improving both objectively measured urinary loss and perceived pelvic floor symptoms.

Keywords: urinary incontinence; multimodal intervention; moderate physical activity; pelvic floor disorders; menopause



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1. Introduction

Urinary incontinence (UI), defined as a condition characterized by the involuntary loss of urine, is caused by a dysfunction of the pelvic floor muscles. Although it can occur in both sexes, it is much more frequent in women, especially after pregnancy or with aging [1].

Article

Physical Activity, Sleep Patterns, and Their Association in Youth with Type 1 Diabetes Before and During a Structured Summer Camp

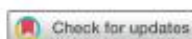
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Abstract

Background: Youth with type 1 diabetes (T1D) often show low physical activity levels and a long time spent in sedentary and poor sleep, which may worsen their health. This study aimed to describe baseline movement and sleep patterns in children and adolescents with T1D and compare them with behaviors recorded during a structured summer camp. **Methods:** Twenty-three participants (13.33 ± 2.13 years) completed physical fitness tests, self-report questionnaires, and 7–8 days of wearable monitoring before camp. During a 10-day diabetes summer camp, participants continued wearing the devices to track physical activity, sedentary time, and sleep. Comparisons between pre- and during-camp periods were performed using paired statistics, and linear regressions examined associations between activity and sleep awakenings. **Results:** At baseline, device-based monitoring showed low physical activity levels, long sedentary time and poor sleep. Self-reported data confirmed low activity levels and long time spent in sedentary activities, especially screen time. During camp, daily steps increased significantly ($p < 0.001$), as well as all the physical activity intensities ($p < 0.01$). Sedentary time decreased significantly ($p < 0.001$), and sleep duration declined ($p < 0.001$), but awakenings were shorter ($p = 0.005$). Baseline sedentary time predicted longer nocturnal awakenings, while greater increases in steps during camp correlated with longer awakenings. **Conclusions:** Children and adolescents with T1D showed low baseline activity, high sedentary time, and poor sleep. Participation in the structured summer camp appears to be associated with changes in physical activity, sedentary behavior, and sleep patterns.

Keywords: wearable devices; physical activity; sleep quality; type 1 diabetes; pediatric diabetes; summer camp



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