Impact and sustainability evaluation of the *KaziKidz* physical activity and health promotion intervention in public primary schools in South Africa

Inaugural dissertation

to

be awarded the degree of Dr. sc. med.

presented at
the Faculty of Medicine
of the University of Basel

by

Patricia Arnaiz

From Pamplona, Spain

Basel 2023

Approved by the Faculty of Medicine

On application of

Faculty representative	Prof. Dr. Uwe Pühse
First supervisor	Prof. Dr. Uwe Pühse
Second supervisor	Prof. Dr. Markus Gerber
External expert	Prof. Dr. Catherine Draper
Further advisor	Prof. Dr. Manfred Max Bergman
Further advisor	Dr. Ivan Müller

Basel, 11th December 2023

Prof. Dr. Primo Schär

Dean

Table of content

Figures and tables

Chapter 8. Synthesis and discussion

Acknowledgements

First and foremost, I would like to express my deep appreciation to my supervisors and advisors. A sincere thank you to Prof. Uwe Pühse for giving me the opportunity to pursue my PhD in the *KaziBantu* project. Thank you for welcoming me into the team even before the project's commencement, allowing complete research autonomy to pursue my interests, and understanding both my professional and personal needs. I am grateful to Prof. Markus Gerber for always having your door open and providing consistent support throughout the research process. My utmost thanks to Dr. Ivan Müller, the rock of the team, neither the project nor I would be where we are today if it wasn't for your selflessness and tireless dedication. Thank you also to Prof. Max Bergman for your guidance in qualitative and mixed-methods research, as well as the thought-provoking insights shared during our conversations. Lastly, I would like to extend my gratitude to Prof. Catherine Draper for kindly agreeing to serve as the external expert on my PhD committee.

My warmest gratitude goes to the entire *KaziBantu* team. I extend a special mention to Prof. Cheryl Walter and Prof. Rosa du Randt for your insights into the South African context and commitment to driving positive change. This project would not be possible without the efforts, knowledge, and dedication of the entire team, and for that, I am truly grateful. My most sincere thank you to my colleague and friend, Dr. Danielle Dolley, for our heart-warming conversations and writing retreats, for (literally) offering me a home in South Africa, and for proof-reading this thesis. Special thanks to Nandi Joubert for always being up for a discussion and having a word of advice, as well as for providing valuable feedback that helped improved this thesis. Thank you also to Larissa Adams, Dr. Siphesihle Nqweniso, Madeleine Nienaber, Sesethu Ncanywa, Zaahira Ismail, and Jan Degen, your unwavering contributions and support have been indispensable.

Furthermore, I would like to thank the DSBG "Villa" team for your warm and supportive atmosphere. A especial thank you to Dr. Harald Seelig for your guidance and patient responses to my many "short" questions. I am especially grateful to Johanna Beckman for your welcoming nature and for making this journey much easier and fun, as well as to the rest of "las chicas", Katharina Klappe, Marina Wälti, and Vera Looser, for your companionship and friendship. Thank you to Dr. Manuel Hacke for providing valuable feedback to this thesis and Dr. Christin Lang for our engaging, not always work-related, conversations. I also would like to extend my thanks to the rest of the DSBG PhD crew, especially Eric Lichtenstein for the training and laughter.

My journey has been enriched by the support and encouragement of friends, both near and far. Thank you to my friends in Basel, Oliver and Idil, Coline and Mathias, Raquel and Roby, Marta and Silvia, and others, who have accompanied me throughout these years. A sincere thank you to my dear friends, Maitea and Nacho, my home away from home, for guiding me and giving me the final push I needed to embark on this adventure. I am grateful to Maria José for our inspiring life-work conversations and helping me deepen my understanding of Implementation Science. I am also grateful to my friends in Pamplona, whose friendship travels distance and time, as well as my university friends, whose experiences and enthusiasm have been a source of inspiration. My warmest thanks go to Jaisalmer for your support during the writing process and your interest and helpful feedback on this thesis.

Last but not certainly least, none of this would have been possible without the love and support of my family. I want to thank my sister and, especially, my parents for always believing in me and providing everything I needed to reach this point. Finally, my most heartfelt thank you goes to my life partner, Conrad. I am forever grateful for your support, patience, and understanding. Your kind, positive, and adventurous spirit are a constant source of motivation and strength.

List of abbreviations

BMI	Body-mass index
COVID-19	Coronavirus Disease 2019
CVD	Cardiovascular disease
DALYs	Disability-adjusted life years
DASH	Disease, activity and schoolchildren's health
GAPPA	Global action plan on physical activity
HbA1c	Glycated haemoglobin
HDL	High-density lipoprotein
HICs	High-income countries
LMICs	Low- and middle-income countries
Mdn	Median
MVPA	Moderate-to-vigorous intensity physical activity
NCD	Non-communicable disease
OR	Odds ratio
PAQ-C	Physical Activity Questionnaire for Children
RCT	Randomised controlled trial
RE-AIM	Reach, Effectiveness, Adoption, Implementation, Maintenance
SDG	Sustainable Development Goal
SLPs	Short Learning Programmes
TC	Total cholesterol
WHO	World Health Organization

Summary

Background: Non-communicable diseases (NCDs) are the leading cause of death and disability worldwide, disproportionately affecting low- and middle-income countries (LMICs). Behavioural risk factors, notably insufficient physical activity, contribute significantly to cardiometabolic changes associated with NCDs. Extensive research has demonstrated the prevalence of these risk factors in children and adolescents and their tracking into adulthood. Yet, evidence from sub-Saharan Africa is scarce. Early identification of cardiovascular risk and promotion of healthy, active lifestyles from a young age are vital to prevent NCDs later in life. This is especially relevant in socioeconomically disadvantaged communities in LMICs, including South Africa, where health inequalities and physical activity barriers are prevalent. In such settings, schools acquire particular importance for shaping physical activity and health habits among children. Therefore, there is a pressing need for context-specific, comprehensive, cost-effective interventions to strengthen physical and health education in South African under-resourced schools. However, ensuring the sustainment and real-world effectiveness of such interventions poses a substantial challenge and warrants thorough evaluation.

Aims: This PhD thesis aimed to evaluate the *KaziKidz* physical activity and health promotion programme, a sub-initiative from the *KaziBantu* project, during its sustainability phase in public primary schools from South Africa. The specific objectives included assessing the identification of physical activity and cardiovascular risk as well as their association in South African children, examining short-term intervention effects on NCD risk factors and their long-term development in high-risk children, exploring stakeholder acceptability and perceived feasibility, and evaluating the programme's continuity in participating schools.

Methods: *KaziKidz* was implemented in the context of the *KaziBantu* randomised controlled trial across eight quintile 3 schools in low-income areas near Gqeberha, South Africa. Four schools served as controls, and four implemented the intervention receiving teaching materials. One intervention school was additionally supported by teacher workshops, one by a physical education coach, and a third one by both. Intervention's efficacy was assessed on children's (n = 961) self-reported and accelerometer-captured physical activity, body-mass-index, blood pressure, serum lipids, and plasma glucose. Quantitative measurements were gathered twice, at baseline (January 2019) and after a 20-week intervention period (October 2019). A follow-up mixed-methods study

was conducted two years' post-intervention (October 2021) during the programme's sustainability phase. Quantitative data were collected from a sub-cohort of high-risk children (n = 280), who presented at least one NCD risk factor, namely overweight, elevated blood pressure, dyslipidaemia, or hyperglycaemia. Qualitative assessments encompassed semi-structured interviews with school principals (n = 3) and focus group interviews with teachers (n = 16) and caregivers (n = 16). The implementation science RE-AIM framework guided the comprehensive evaluation of *KaziKidz* using a mixed-methods convergent design.

Results: Divergent results were observed between instruments assessing paediatric hypertension and physical activity and their association with cardiovascular risk, demonstrating the need for evidence-based, context-appropriate methodologies for identifying risk in South African children. In terms of short-term intervention efficacy, *KaziKidz* positively impacted moderate-to-vigorous physical activity levels among girls at school and improved mean arterial pressure of children as well as cholesterol and glucose levels of non-high-risk children. Nevertheless, research is needed to determine the benefit of specific intervention components for distinct subgroups and further enhance physical activity levels for all children inside and outside of school. School staff and caregivers emphasised the programme's significance for children, but called for increased involvement and external support to deliver and sustain the programme in schools. The evaluation of the intervention's sustainability was hampered by the Coronavirus Disease 2019 (COVID-19) pandemic and closure of schools, resulting in the discontinuation of *KaziKidz*. Furthermore, a decline of health outcomes among high-risk children was observed in the long-term. Accounts from school personnel suggested that, under normal circumstances, maintaining the programme without additional support would have been challenging.

Conclusion: Public schools are pivotal platforms for ensuring quality physical education, providing physical activity opportunities for all children, and promoting healthy behaviours in disadvantaged communities in South Africa. *KaziKidz*'s holistic approach holds promise for improving risk factors for NCDs, but ensuring intervention continuity is imperative for sustaining long-lasting health benefits. In-service training should enhance programme ownership among non-specialist teachers and be supported by implementation coaching, school administration engagement, and political commitment. Evaluating the feasibility of these measures and the

effectiveness and fidelity of *KaziKidz*'s delivery upon resumption is recommended to refine the programme and guide its scale-up.

Zusammenfassung

Hintergrund: Nicht übertragbare Krankheiten (NCDs) sind weltweit die Hauptursache für Tod und Behinderung, wobei Länder mit niedrigem und mittlerem Einkommen (LMICs) unverhältnismäßig stark betroffen sind. Verhaltensbedingte Risikofaktoren, insbesondere unzureichende körperliche Aktivität, tragen maßgeblich zu den kardiometabolischen Veränderungen bei, die mit NCDs einhergehen. Umfangreiche Forschung hat die Prävalenz dieser Risikofaktoren bei Kindern und Jugendlichen nachgewiesen und sie bis ins Erwachsenenalter nachverfolgt. Es gibt jedoch nur wenig Evidenz aus Subsahara-Afrika. Die frühzeitige Erkennung von kardiovaskulären Risiken und die Förderung eines gesunden, aktiven Lebensstils von klein auf sind entscheidend für die Prävention von NCDs im späteren Leben. Dies ist besonders wichtig in sozioökonomisch benachteiligten Gemeinden in LMICs, einschließlich Südafrika, wo Gesundheitsungleichheiten und Hindernisse für körperliche Aktivität weit verbreitet sind. In einem solchen Umfeld kommt den öffentlichen Schulen eine besondere Bedeutung bei der Gestaltung von körperlicher Aktivität und Gesundheitsgewohnheiten bei Kindern zu. Daher besteht ein dringender Bedarf an kontextspezifischen, umfassenden, und kosteneffizienten Interventionen zur Stärkung der Bewegungs- und Gesundheitserziehung in südafrikanischen unterversorgten Schulen. Die Sicherstellung der Nachhaltigkeit und der realen Wirksamkeit dieser Interventionen stellt jedoch eine große Herausforderung dar und erfordert eine gründliche Evaluierung.

Ziele: Diese Doktorarbeit hatte zum Ziel das *KaziKidz*-Programm, eine Unterinitiative des Projekts *KaziBantu*, zur Förderung von körperlicher Aktivität und Gesundheit während seiner Nachhaltigkeitsphase in öffentlichen Grundschulen in Südafrika zu evaluieren. Die spezifischen Ziele umfassten die Bewertung der Identifizierung von körperlicher Aktivität und kardiovaskulärem Risiko sowie deren Zusammenhang bei südafrikanischen Kindern, die Untersuchung der kurzfristigen Interventionseffekte auf NCD-Risikofaktoren und deren langfristige Entwicklung bei Hochrisikokindern, die Untersuchung der Akzeptanz und wahrgenommenen Machbarkeit durch die Beteiligten sowie die Bewertung der Kontinuität des Programms an den teilnehmenden Schulen.

Methoden: *KaziKidz* wurde im Rahmen der randomisierten kontrollierten Studie *KaziBantu* in acht Schulen der Quintil-Klasse 3 in einkommensschwachen Gebieten in der Nähe von Gqeberha,

Südafrika, umgesetzt. Vier Schulen dienten als Kontrollgruppe, während Vier die Intervention durchführten und Unterrichtsmaterialien erhielten. Eine Interventionsschule wurde zusätzlich durch Lehrerworkshops unterstützt, eine Weitere durch eine:n Sportlehrer:in und eine Dritte durch beides. Die Wirksamkeit der Intervention wurde anhand der selbstberichteten und Beschleunigungsmesser-erfassten körperlichen Aktivität, des Body-Mass-Index, des Blutdrucks, der Serumlipide und des Glukosespiegels von Kindern (n = 961) bewertet. Quantitative Messungen wurden zweimal erhoben, zu Beginn (Januar 2019) und nach einer 20-wöchigen Interventionsphase (Oktober 2019). Eine Folgeuntersuchung mit gemischten Methoden wurde zwei Jahre nach Interventionsende (Oktober 2021) während der Nachhaltigkeitsphase des Programms durchgeführt. Quantitative Daten wurden von einer Teilkohorte von Hochrisikokindern (n = 280) gesammelt, die mindestens einen NCD-Risikofaktor aufwiesen, nämlich Übergewicht, erhöhten Blutdruck, Dyslipidämie oder Hyperglykämie. Qualitative Bewertungen umfassten halbstrukturierte Interviews mit Schulleitern:innen (n = 3), sowie Fokusgruppeninterviews mit Lehrern:innen (n = 16) und Betreuern:innen (n = 16). Das RE-AIM-Modell der Implementierungswissenschaft diente als Grundlage für die umfassende Evaluierung von *KaziKidz* unter Verwendung eines konvergenten Designs für die gemischten Methoden.

Ergebnisse: Es wurden unterschiedliche Ergebnisse zwischen den Instrumenten zur Bewertung von Bluthochdruck und körperlicher Aktivität bei Kindern sowie deren Zusammenhang mit kardiovaskulären Risiken festgestellt, was den Bedarf an evidenzbasierten, kontextgerechten Methoden zur Risikoermittlung bei südafrikanischen Kindern aufzeigt. Hinsichtlich der kurzfristigen Wirksamkeit der Intervention hatte *KaziKidz* einen positiven Einfluss auf das Niveau mäßiger bis intensiver körperlicher Aktivität bei Mädchen in der Schule und verbesserte den mittleren arteriellen Druck der Kinder sowie die Cholesterin- und Glukosewerte von Kindern ohne erhöhtes Risiko. Dennoch sind weitere Forschungsarbeiten erforderlich, um den Nutzen bestimmter Interventionskomponenten für verschiedene Untergruppen zu ermitteln und das Bewegungsniveau aller Kinder innerhalb und außerhalb der Schule weiter zu steigern. Schulpersonal und Betreuer:innen betonten die Bedeutung des Programms für die Kinder, forderten jedoch eine stärkere Beteiligung und externe Unterstützung, um das Programm in den Schulen durchführen und aufrechterhalten zu können. Die Bewertung der Nachhaltigkeit der Intervention wurde durch die Coronavirus-Krankheit 2019 (COVID-19) Pandemie und die Schließung von Schulen beeinträchtigt, was zur Unterbrechung von *KaziKidz* führte. Darüber

hinaus wurde langfristig ein Rückgang der Gesundheitsergebnisse bei Hochrisikokindern beobachtet. Aus Berichten des Schulpersonals geht hervor, dass die Aufrechterhaltung des Programms unter normalen Umständen ohne zusätzliche Unterstützung eine Herausforderung gewesen wäre.

Fazit: Öffentliche Schulen spielen eine entscheidende Rolle bei der Sicherstellung qualitativ hochwertigen Sportunterrichts, der Bereitstellung von Bewegungsmöglichkeiten für alle Kinder und der Förderung gesunder Verhaltensweisen in benachteiligten Gemeinschaften in Südafrika. Der ganzheitliche Ansatz von *KaziKidz* ist vielversprechend, um die Risikofaktoren für NCDs zu verbessern, jedoch ist die Gewährleistung der Kontinuität der Intervention unerlässlich, um einen langfristigen Nutzen für die Gesundheit zu erzielen. Lehrerworkshops sollten die Eigenverantwortung von Lehrern, die keine Fachleute sind, für das Programm stärken und durch Umsetzungscoaching, Einbindung der Schulleitung und politisches Engagement unterstützt werden. Es wird empfohlen, die Durchführbarkeit dieser Maßnahmen sowie die Effektivität und Zuverlässigkeit der Umsetzung von *KaziKidz* nach Wiederaufnahme zu bewerten, um das Programm zu optimieren und seine Ausweitung zu steuern.

Chapter 1. Introduction

This PhD thesis presents a comprehensive evaluation of the *KaziKidz* health promotion intervention during its sustainability phase in public primary schools from South Africa. *KaziKidz* was implemented as part of the *KaziBantu* project in 2019 with the aim of enhancing children's physical activity levels and improving risk factors for noncommunicable diseases in educational settings. Subsequently, a follow-up mixed-methods study was conducted in 2021 to investigate the long-term effects of the intervention as well as its continuation during the sustainability phase of the project, i.e. after intervention completion, cease of external support, and under real-world conditions. The current evaluation is positioned in the backdrop of the Coronavirus Disease (COVID-19) pandemic declared in 2020. The ensuing lockdown measures, most notably the closure of schools, significantly disrupted the continuity of the intervention under study.

This first chapter delves into the nature, prevalence, and implications of noncommunicable diseases and physical inactivity , with a specific focus on children and the context of South Africa. Following, attention is given to strategies aimed at mitigating their burden, specifically through prevention programmes conducted in schools , alongside an overview of the existing initiatives in South Africa. The chapter finalises with a detailed description of the *KaziKidz* intervention .

1.1. Noncommunicable diseases

Non-communicable diseases (NCDs) are a collection of not transmissible, chronic conditions that are characterised by their gradual development and often asymptomatic beginnings (World Health Organization, n.d.-a). Over time, they lead to dysfunction and compromised health, thereby diminishing the quality of life throughout the life course and resulting in premature mortality. Being the leading cause of mortality and disability worldwide, recent estimations indicate that NCDs accounted for 42 million deaths globally, with 17 million occurring before the age of 70, and the loss of 1.6 billion healthy life years in 2019 (measured as disability-adjusted life years - DALYs) (Institute for Health Metrics and Evaluation, 2020). Among these conditions, four disease clusters—cardiovascular diseases (CVDs), cancers, chronic pulmonary diseases, and diabetes—contribute to roughly 80% of NCD-related deaths. Particularly, CVDs have a leading role in the NCD burden and have contributed to the rise in NCD cases, with CVDs prevalence nearly doubling

from 271 to 523 million between 1990 and 2019 (Global Burden of Disease 2019 Cardiovascular Diseases Writing Group, 2020).

The origin of many NCDs can be traced back to societal conditions, commonly referred to as lifestyle or behavioural risk factors, with poor diets, physical inactivity, tobacco use, and alcohol abuse being recognised as the four most prominent contributors (World Health Organization, n.d.-a). As a result of these lifestyle risk factors, physiological changes occur, which manifest as increased weight, high blood pressure, elevated blood glucose, and abnormal lipid levels. Indeed, the impact of such cardiometabolic risk factors on overall disease burden is substantial, as evidenced by the ranking of high systolic blood pressure, high plasma glucose, and high body-mass index (BMI) among the top five leading risks for all-cause mortality and disability in 2017 (Global Burden of Disease 2017 Risk Factor Collaborators, 2018).

However, it is essential to recognise that chronic conditions stem from a complex interplay of various factors, encompassing the mentioned behavioural aspects alongside socioeconomic circumstances, environmental conditions, genetic predisposition, and others (Tulchinsky et al., 2023). For instance, changes in socioeconomic factors and mass movement of people to cities are associated with lifestyle modifications characterised by more sedentary behaviours and access to calorie-rich diets (Fazeli Dehkordi et al., 2022; Mashili et al., 2018; Ndubuisi, 2021). It has been shown that obesity prevalence increases with income in nations with lower development levels (Broyles et al., 2015). Consequently, the necessary and inevitable economic growth of nations comes at the expense of a mounting incidence of NCDs.

1.1.1. The case of South Africa

Low- and middle-income economies are undergoing a shift in disease patterns characterised by a decrease in deaths caused by infectious agents, malnutrition, and maternal and child diseases and an increase in morbidity and mortality associated with NCDs (Frenk et al., 1989). This shift was first described by Omran (1971) in the epidemiological transition theory. Evidence indicates that this change is occurring at a faster pace compared to high-income countries (HICs), with transitioning economies currently facing a double burden of disease (Santosa & Byass, 2016). Meanwhile, their health systems, fundamentally focused on combating infectious diseases, are ill-prepared to cope with the burden posed by NCDs (NCD Alliance, n.d.).

low- and middle-income countries (LMICs) and in particular sub-Saharan Africa bear the brunt of the NCD mortality burden, accounting for 85% of all premature deaths globally. (NCD Countdown 2030 collaborators, 2020). By 2030, NCDs are projected to surpass infectious, maternal and neonatal, and undernutrition-related diseases to become the leading cause of disability in Africa (Agyepong et al., 2017). This surge in NCD cases is primarily driven by rampant increases in CVDs and diabetes, and continues to rise in southern African countries. In South Africa, recent national estimates indicate that diseases of the cardiovascular system have overtaken infectious agents as the leading cause of mortality, signifying an important change since 2009 (Figure 1) (Statistics South Africa, 2018).

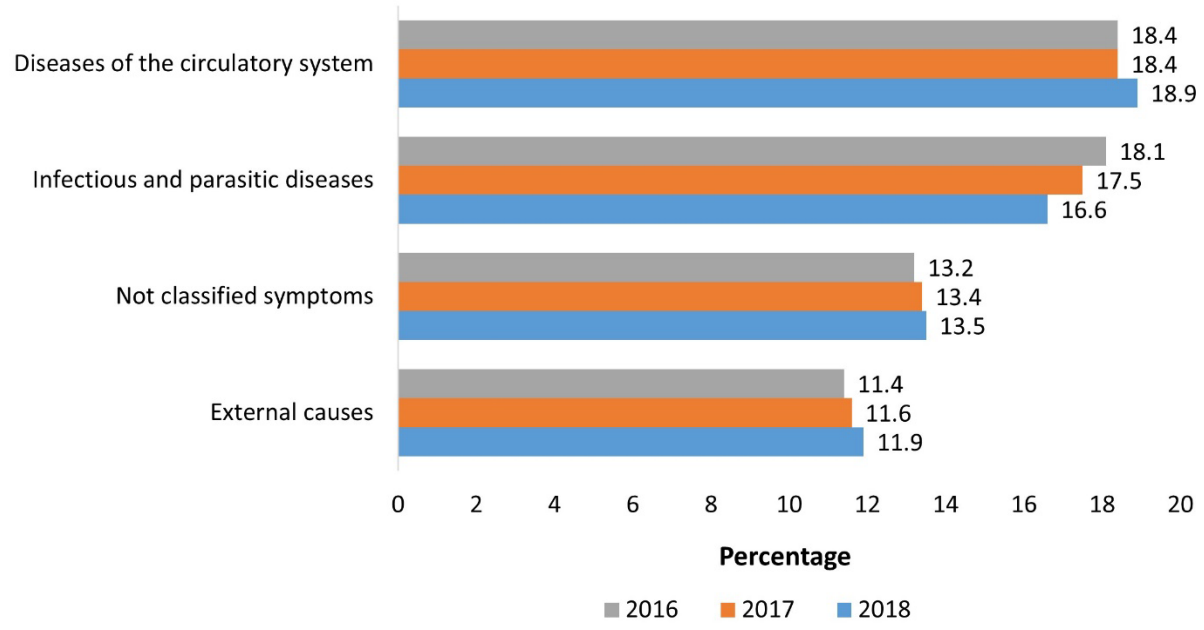

Figure 1. Leading causes of death in South Africa by disease group between 2016 and 2018, adapted from Statistics South Africa (2018).

However, disparities in mortality outcomes from NCDs among population sectors in South Africa have been reported, reflecting persistent health inequalities (Kabudula et al., 2017; Pillay-van Wyk et al., 2016). Concretely, disparities become evident in the scarce access to treatment for NCD risk factors prevalent in poor communities (Bradshaw et al., 2019; Pillay-van Wyk et al., 2016). Indeed, South Africa has poorer health outcomes compared to countries at a similar level of development, which has been ascribed to wealth and health inequalities (Coovadia et al., 2009). Despite being classified as an upper-middle income country by the World Bank, South Africa faces substantial

challenges in terms of poverty and inequality. The Gini index, a measure of inequality, places South Africa as the most unequal country globally, with over 50% of its population living in poverty (World Bank, n.d.). Furthermore, the Human Capital Index, an indicator of country prosperity, reveals that South Africa's current state of health and education is only able to utilise 43% of its citizens' potential to contribute as productive members of society (World Bank, 2020). As a result, the rapidly evolving health and disease landscape in South Africa carries significant implications both for economic progress and poverty alleviation.

These findings underscore the need to re-evaluate the country's public health system to include measures tackling social determinants of health while strengthening the management and prevention of NCDs and their risk factors.

1.1.2. Burden of cardiometabolic risk factors in children

Cardiometabolic NCDs like CVDs and diabetes have typically been attributed to adulthoods because of their late manifestation. Nonetheless, emerging research is shedding light on the early-life origins of these diseases, supported by extensive evidence demonstrating the presence of (generally asymptomatic) metabolic precursors in children (Ajala et al., 2017; Wang et al., 2013).

Global analyses have revealed a 75% increase in paediatric hypertension between 2000 and 2015 (Song et al., 2019). This trend has been observed in Africa as well, with the rampant escalation in childhood obesity being a major contributing factor (Noubiap et al., 2017). Indeed, the largest surge in obesity among children and adolescents worldwide over the past five decades occurred in southern Africa, with an approximate 400% increase each decade (NCD Risk Factor Collaboration, 2017). In South Africa, Armstrong et al. (2011) have reported an upward trend in the prevalence of overweight (from 1.2% to 13%) and obesity (from 0.2% to 3.3%) among school-aged children between 1994 and 2004. Cross-sectional studies have confirmed the widespread existence of risk factors among South African children. A study involving 975 schoolchildren from disadvantaged areas encountered that a significant proportion (43.3%) presented at least one cardiometabolic risk factor (Dolley et al., 2022). In a similar population, approximately every fifth child was overweight, while more than one third displayed signs of hypertension (Gerber et al., 2018; Joubert et al., 2021).

Importantly, it has been observed that these cardiometabolic risk factors track into adulthood (Ajala et al., 2017; Drozdz et al., 2021). Drozdz et al. (2021) found that obesity in adolescence persisted beyond the age of 30 in 70% of cases, while childhood dyslipidaemia, hyperinsulinemia, and hypertension increased cardiovascular risk later in life. Similarly, in LMICs, Joshi et al. (2014) reported the tracking of several CVD risk factors from childhood into adulthood, with the strongest associations described for adiposity and total cholesterol. Consequently, the American Heart Association identifies children with increased adiposity, elevated blood pressure, dyslipidaemia, or insulin resistance to be particularly vulnerable to adverse health outcomes and premature risk for CVDs (de Ferranti et al., 2019).

Moreover, the COVID-19 pandemic has been reported to have worsened the prevalence of risk factors among children and adolescents worldwide (Cena et al., 2021). According to the authors, the accompanying lockdown measures and isolation have favoured unhealthy lifestyles, leading to weight gains in children.

Considering the early onset and escalating burden of preclinical precursors of chronic diseases together with the enhanced risk for CVD development, prioritising the identification and prevention of common risks factors among children and adolescents is crucial for preventing NCDs in the general population.

1.1.3. Surveillance

To effectively assess, monitor, and address disease trends, accurate and detailed epidemiological data is necessary. However, in transitioning economies like South Africa, there is a lack of established surveillance systems to collect comprehensive health information at the population level (Bradshaw et al., 2019). In turn, the dearth of accurate data on NCDs is known to hinder understanding the epidemiology of these diseases and their associated risk factors in sub-Saharan Africa (Gouda et al., 2019). Hence, an urgent need exists to enhance the surveillance of cardiometabolic disease risk in LMICs (Miranda et al., 2019), and in South Africa particularly (Bradshaw et al., 2007).

Furthermore, effective NCD surveillance relies on the availability of appropriate methods to identify the diverse array of risk factors in specific populations. However, despite the consensus on the key individual components constituting cardiometabolic risk, namely adiposity,

hypertension, dyslipidaemia, and glucose intolerance (Andersen et al., 2015), there is a lack of agreement on the most effective approach to identify the risk associated with these risk factors in children (Stavnsbo et al., 2018).

Adiposity

Various reference growth curves, accounting for sex, age, and height, have been developed to define adiposity in children and adolescents (Centers for Disease Control and Prevention, 2000; Cole & Lobstein, 2012; de Onis et al., 2007). Among these, the BMI-for-age norm charts developed by World Health Organization (WHO), based on datasets from 22 countries, are considered the gold standard for determining childhood overweight and obesity in clinical and epidemiological settings worldwide (de Onis et al., 2007; Lobstein, 2017).

Hypertension

Regarding paediatric hypertension, national normative percentiles accounting for sex, age, and sex have been devised, with two of the most widely used originating from the United States and Germany (Flynn et al., 2017; Neuhauser et al., 2011). However, the establishment of a universal reference and the harmonisation of blood pressure assessment and analysis are still pending.

Hyperglycaemia

Moreover, there is an absence of standardised normative charts for plasma glucose, in spite of the recognised transient change in the metabolism of glucose during puberty (Nyangasa et al., 2019). As a result, population-wide cut-offs defined by the American Diabetes Association for glycated haemoglobin (HbA1C) are commonly employed in epidemiology to identify pre- and diabetes in both children and adults (American Diabetes Association, 2020).

Dyslipidaemia

Age- and sex-specific curves have been developed for lipids, mostly on a national or regional scale (Balder et al., 2018; Li et al., 2021; Nielsen et al., 2017; Skinner et al., 2012). Still, the assessment of individual lipid concentrations and the use of unique cut-offs continue to be the prevailing practice at the international level (Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents & National Heart Lung and Blood Institute, 2011).

Furthermore, attempts to establish standardised references for risk parameters reveal a notable underrepresentation of African paediatric populations, hence limiting their applicability in this specific context. For instance, Stavnsbo et al. (2018) have proposed reference values for common cardiometabolic risk factors, albeit based solely on data from European and American children. Similarly, Xi et al. (2016) aggregated data from seven nations to develop global references for blood pressure, none of which originated from sub-Saharan Africa. Importantly, the constrained transferability of metabolic disease risk among racial groups has been acknowledged (Hudda et al., 2022; Nieto-Martinez et al., 2021). Specifically regarding blood pressure, no normative tables for African children exist, while a low consistency between international and national normative values has been noted (Agirbasli et al., 2020).

Given the apparent inadequacy of applying universal references across diverse contexts, ensuring the appropriateness of methods to assess the prevalence of NCD risk factors in the African paediatric population is crucial. This, in turn, will allow to guide effective disease prevention strategies.

1.2. Physical activity

Physical activity is defined as movements executed by skeletal muscles that demand increased energy expenditure and encompasses a broad spectrum of activities, including walking, sports, household chores, and play, to name a few (World Health Organization, n.d.-b). Extensive research has shown that physical activity offers numerous health benefits, with evidence suggesting a dose-response relationship, whereby longer durations and higher intensities yield greater health advantages (Bull et al., 2020; Janssen & LeBlanc, 2010). Notably, physical activity plays a crucial role in the prevention and management of chronic conditions. Indeed, strong and consistent evidence supports the inverse association between total physical activity and adiposity, as well as cardiometabolic risk markers like blood pressure, cholesterol, or fasting glucose (Poitras et al., 2016; Roman-Vinas et al., 2016). Thus, sustained physical activity has emerged as an independent predictor of CVD outcomes and is associated with a lower risk of mortality among adults (Moholdt et al., 2018).

Consequently, low levels of physical activity and sedentary behaviours, defined as energy expenditure below 1.5 metabolic equivalent task while in sitting, reclining or lying (Tremblay et al., 2017), are related to an increased risk for cardiometabolic conditions, with up to a 30% greater

risk of all-cause mortality (World Health Organization, n.d.-b). The global impact of physical inactivity on overall disease burden is substantial, having contributed to the rise of NCDs worldwide (Anderson & Durstine, 2019). In fact, due to the abundance of insufficiently active individuals globally, physical inactivity is now considered a global epidemic (Pratt et al., 2020). The latest global status report on physical activity estimates that between 2020 and 2030, physical inactivity will be responsible for almost 500 million new cases of NCDs, with around 75% occurring in LMICs (World Health Organization, 2022).

Physical inactivity has been ascribed to the adoption of unhealthy habits, specifically sedentary behaviours driven by an increase in inactive recreational activities and screen time coupled with a decrease in active transportation and physically demanding occupations (Kohl et al., 2012). It is important to note that physical activity behaviour is conditioned by a combination of factors that interact with each other (Bauman et al., 2012; Brand & Ekkekakis, 2017; Giles-Corti & Donovan, 2002). On the one hand, personal determinants, such as age, sex, preferences, and inherent motivation strongly shape individual engagement in physical activities. On the other hand, social support and the environment play a significant role in influencing the personal motivation and providing opportunities for physical activity (Giles-Corti & Donovan, 2002; Haughton McNeill et al., 2006). Moreover, the impact of policies at local, regional, or national levels cannot be underestimated, as they have the potential to influence population-wide behaviours over extended periods (Bauman et al., 2012).

In conclusion, it becomes evident that prioritising the promotion of active lifestyles with context-appropriate interventions is essential to effectively address the considerable health burden associated with NCDs.

1.2.1. The case of South Africa

Africa in general and South Africa in particular are witnessing a rapid growth of urban settlements that is transforming the structure of cities (Weimann & Oni, 2019). The expansion of cities brings about significant environmental changes, including the conversion of green spaces into built-up areas, increased motorised transportation, and the disappearance of pavements, resulting in reduced levels of daily physical activity (Juma et al., 2020). Notably, several studies have affirmed that adults and children residing in urban areas of sub-Saharan Africa, concretely in South Africa, engage in lower levels of activity compared to their rural counterparts (Mabweazara et al., 2019;

Mashili et al., 2018; Wachira et al., 2022). Safety concerns from crime and traffic add to the unfavourable built environment as major barriers for engaging in recreational physical activity in upper-middle countries like South Africa (Oyeyemi et al., 2021). Consequently, the low prioritisation of physical activity in these settings is evident, where active behaviours result from "need" rather than "choice" (Lambert et al., 2020). This prioritisation is reflected in the South African education system, where physical education holds a lower status than academic subjects.

Physical education

Over the past decades, physical education in South Africa has undergone significant developments. During the apartheid era, physical education curricula varied among schools based on ethnic groups, leading to privileged, white schools having more comprehensive syllabi and greater opportunities for physical activity compared to other schools (Stroebel et al., 2016). The end of apartheid brought about an educational reform (Department of Education, 1997) that resulted in physical education losing its standalone subject status in 1998, and in its integration into the broader learning area of Life Skills for grades R to 6 and Life Orientation for grades 7 to 12 (Department of Basic Education, 2011a, 2011b, 2011c). These subjects comprise, besides physical education, other learning areas such as beginning knowledge, personal and social wellbeing, and creative arts. As a consequence of the integration, the emphasis on physical education diminished, leading to reduced curriculum time for this learning area. Moreover, the responsibility for teaching physical education shifted from specialists to generalist educators, posing further challenges such as low teaching competency and motivation, especially in low-resourced schools (Burnett, 2020; Draper et al., 2010a; Stroebel et al., 2017).

The apartheid legacy continues to manifest in the unequal availability and condition of sports facilities and equipment between historically advantaged and disadvantaged schools (Draper et al., 2010a; Stroebel et al., 2016). A comprehensive investigation into the current state of physical education in South Africa confirmed that schools situated in lower-income settings like townships and rural areas, still face resource limitations, which significantly hinder the effective delivery of physical education (Stroebel, 2020). Further challenges include competing priorities, high workload, staff turnover, large class sizes, and insufficient funds, to name a few (Draper et al., 2010a; Hill et al., 2015; Stroebel, 2020). Furthermore, the limited opportunity for physical activity participation in these schools extends beyond the scope of physical education and arises as well

from the absence of, or inaccessibility to, organised sports, activity clubs, or chances for outdoor play (Van Hout et al., 2013; Vosloo & du Toit, 2023).

Hence, strengthening the delivery of physical education in schools from low-income areas in South Africa is essential to provide more opportunities for children to partake in physical activities within the school environment.

1.2.2. Burden of physical inactivity in children

The association between physical activity and improved cardiovascular health has also been observed in children (Climie et al., 2021; Janssen & LeBlanc, 2010). In addition, recent research indicates that the former can enhance the mental health and cognitive development of children and adolescents (Carney & Firth, 2021; Dzhambov et al., 2023). Other benefits known to be important in promoting human capital, particularly academic achievement and motor and social skills, have also been reported to improve with regular physical activity (Bull et al., 2020; Haugland et al., 2023; Michael et al., 2015) and physical education (Ramires et al., 2023). Given that the positive impact of regular physical activity on cardiometabolic risk factors (Gerber et al., 2018; Moselakgom & Staden, 2018; Müller et al., 2020), fundamental movement skills (van Niekerk et al., 2016), and quality of life (Gall et al., 2020) has been confirmed for South African children, the limited availability of physical education and recreational opportunities in low-income communities in South Africa is particularly concerning.

Current guidelines for children and adolescents aged 5 to 17 recommend a minimum of 60 minutes per day of moderate-to-vigorous intensity physical activity (MVPA) (Bull et al., 2020). However, global estimates reveal that a significant proportion of school-aged adolescents fail to meet these recommendations, with 81% worldwide falling short in 2016, and a higher prevalence observed in sub-Saharan Africa (86.2%) (Guthold et al., 2020). Similarly, Xu et al. (2020) found that only 16.6% of children in the African region achieve the recommended MVPA levels .

However, it is important to note two shortcomings when estimating the prevalence of physical inactivity among children and adolescents. Firstly, data availability is scarce in certain regions. A study on the global trends in physical inactivity among adolescents revealed that only 30% of countries from sub-Saharan Africa had data available (Guthold et al., 2020). Secondly, the estimated prevalence varies greatly in the literature, primarily attributed to inconsistent

measurement methodologies (Aubert et al., 2021). In South Africa, the absence of nationally representative data poses a significant challenge in assessing the prevalence of insufficient physical activity. Based on regional samples, the prevalence ranges from 23% to 73% (Muthuri et al., 2016; Naidoo et al., 2022; Salvini et al., 2018; Sedumedi et al., 2021; Van Biljon et al., 2018). Relying on inaccurate and discrepant prevalence of physical inactivity rates may result in an underestimation of the problem, consequently hindering its prioritisation on the public health agenda.

Along these lines and despite the global endorsement of physical activity over the past two decades (World Health Organization, 2010), global trends show limited progress in reducing the prevalence of physical inactivity among school-aged children (Guthold et al., 2020). Moreover, the COVID-19 pandemic has further exacerbated the conundrum by negatively impacting the physical activity levels of the general population (Cena et al., 2021). The closure of schools during the pandemic has deprived children of opportunities to engage in physical activity, especially in communities where options for sports and recreation are limited (World Health Organization, 2022).

The high prevalence of insufficiently active youth emphasises the urgency to promote health-enhancing physical activity to prevent the development of NCDs in the long run and, especially among children living in disadvantaged settings, foster human capital. Moreover, the scarcity of available data and disparities in physical inactivity estimates in certain regions call for the harmonisation of its measurement to enhance the reliability of physical activity surveillance.

1.2.3. Surveillance

Broadly, two main categories of instruments are used to assess physical activity: self-reported and device-based methodologies. Self-reported methods include tools such as questionnaires, diaries, or observations, while device-based instruments utilise accelerometers, pedometers, and heart rate monitors among others (Prince et al., 2008). Device-based technology offers higher accuracy and the ability to measure intensity, duration, and frequency of movement. Meanwhile, it is also associated with higher costs and time requirements as well as a series of subjective decisions, including analysis algorithms, non-wear-time definitions, or cut points for different intensities among others (Skender et al., 2016). Self-reported methods provide a cost-effective alternative, allowing for larger population coverage in a shorter timeframe without requiring expensive technological solutions (Chinapaw, 2010). However, they are also prone to recall bias and social

desirability leading to a tendency to overestimate activity levels, especially in youth (Chinapaw, 2010). As a consequence, LMICs, and concretely South Africa, predominantly use self-reported methods, while HICs tend to rely on wearable devices (Guthold et al., 2020; Klingberg et al., 2019; van Sluijs et al., 2021). The use of varied assessment methods further hampers the monitoring and comparability of the prevalence of physical inactivity (Errisuriz et al., 2018; Guthold et al., 2020).

Numerous studies have shown inconsistencies between assessment methods. Particularly for self-reported and wearable devices, a systematic review found only moderate convergent validity between the Physical Activity Questionnaire for Children (PAQ-C) and accelerometer-measured MVPA, suggesting that each method might assess different constructs of physical activity in children (Marasso et al., 2021). Monyeki et al. (2018) similarly observed limited agreement in physical activity assessments between an accelerometer device and a brief questionnaire in South African adolescents. In addition, Pedisic and Bauman (2015) evidence a poor generalisability and validity of accelerometry findings ascribed to the absence of consensus on data collection and standardisation. The incongruent validity of measurement instruments and limited generalisability of results signal that questions persist regarding the most suitable method for surveillance purposes.

To monitor progress in physical activity levels and its impact on improved health in lower-income nations, it is important to rely on appraisal tools that are sensitive to the cultural context and the pattern of physical activity and disease in the population. The relationship between physical activity and health outcomes in LMICs and underserved communities, especially among children, remains an evidence gap (Bull et al., 2020). Some studies have explored the association of physical activity with cardiometabolic markers in the South African context (Gerber et al., 2018; Müller et al., 2020; Nqweniso et al., 2021b; Sedumedi et al., 2021), yet, few have compared different methodologies in their relationship with cardiovascular risk. Thus, a better understanding of how assessment methodologies and specific movement constructs correlate with risk outcomes in certain populations can advance health and physical activity surveillance.

In conclusion, accurate representation of the true burden of physical inactivity in the society is crucial to convince decision makers and galvanise public support for health and physical activity promotion.

1.3. Health and physical activity promotion

1.3.1. Call to action

The burden of NCDs has become increasingly apparent in recent years, prompting governments worldwide to acknowledge their responsibility in addressing this challenge (McBride et al., 2019). In 2013, the WHO endorsed the "Global action plan for the prevention and control of NCDs 2013–2020" to support national efforts and foster international cooperation in adapting to the evolving disease pattern (World Health Organization, 2013). Subsequently, the United Nations incorporated the fight against NCDs into the Sustainable Development Goal (SDG) number 3 "Ensure healthy lives and promote well-being for all at all ages". Since then, South Africa and other influential economies have committed to supporting the global health agenda against NCDs (McBride et al., 2019). Yet, the first analysis of progress towards SDG target 3.4, aimed at reducing premature mortality from NCDs by one third before 2030, has revealed that the improvement pace is insufficient to achieve this objective (NCD Countdown collaborators, 2018).

Notably, treating apparent NCD and metabolic risk factors to avoid immediate mortality and disability will not be sufficient to halt the increase and reduce the incidence of chronic conditions. Primary prevention, instead, reduces vulnerability to disease development by addressing macro-level factors to create advantageous physical, social, and policy environments (Bloom et al., 2011). Modern public health thus requires comprehensive actions beyond the health system to tackle modifiable risk factors in the population (Tulchinsky et al., 2023). However, research suggests that African countries are lagging behind in prioritising health promotion interventions and implementing policies to prevent the underlying risk factors driving the NCD epidemic (Juma et al., 2020). This challenge is mainly driven by African nations being compelled to make choices on how to allocate their limited resources among competing public priorities.

Paralleling the growing awareness of NCDs, the significance of physical activity in improving health and reducing cardiometabolic risk has gained increased recognition in the global public health community (Ding et al., 2020). Thus, similar international initiatives have been established to lessen the burden of physical inactivity. Most notably, WHO member states approved the "Global Action Plan on Physical Activity (GAPPA) 2018–2030", setting a target to reduce insufficient physical activity levels by 15% among adults and adolescents worldwide by 2030

(World Health Organization, 2018). Despite these efforts, evidence has shown that ineffective operationalisation of physical activity policies has led to implementation gaps, resulting in the stagnant rates of physical inactivity (Volf et al., 2023; World Health Organization, 2022). To address this shortcoming, the GAPPA advocates combining broader inter-sectoral policies with targeted individual strategies (World Health Organization, 2018). Concretely, strategy 3.1. "Enhance physical education and school based programmes" (p. 45) highlights the importance of educational settings in supporting enhanced physical activity to foster long-term positive health outcomes in the population. Hence, the education sector is considered key in the fight against NCDs, especially in LMICs (Ndubuisi, 2021).

As described above, many cardiometabolic dysfunctions have their origin in unhealthy behaviours. In turn, these habits are typically acquired during childhood and adolescence (Uddin et al., 2020). Importantly, consistent findings indicate that physical activity declines with age, particularly during adolescence (Aubert et al., 2021; Dumith et al., 2011), and that inactivity patterns track into adulthood (Corder et al., 2019; van Sluijs et al., 2021). Given that inactive children and those presenting premature signs of CVDs are at greater health risk later in life, intervening early in life is crucial for instilling and reinforcing healthy habits and effectively preventing the development of NCDs. Thus, disease prevention initiatives must broaden their focus to modify health habits, with a strong emphasis on prompting increased physical activity among underprivileged populations, younger age groups, and children with an elevated cardiovascular risk.

1.3.2. School-based programmes

Schools serve as a formal and stable structure to reach a large proportion of children from various socioeconomic backgrounds. Interestingly, schools, and particularly primary schools, possess the unique capacity to influence habits from an early age, making them an ideal environment to promote physical activity and healthy lifestyles (Carson et al., 2014; Naylor & McKay, 2009). Given that children and adolescents spend a considerable portion of their day at school, it also presents an excellent opportunity to help them achieve the recommended daily physical activity (Naylor & McKay, 2009).

Particularly physical education ensures the formal provision of physical activity in schools. Physical education plays a crucial role in teaching movement skills, fostering positive attitudes towards exercise, and instilling the value of lifelong engagement in physical activity for the next

generations (Ramires et al., 2023; Yuksel et al., 2020). Research has demonstrated that participation in physical education is associated with increased physical activity in nations across the globe (Cheung, 2017; Silva et al., 2018). Nonetheless, physical education alone will not suffice to help children and adolescents achieve the recommended daily minimum physical activity. Firstly, the time spent in MVPA during physical education lessons has been reported to contribute minimally to total MVPA levels throughout the week (Johansen et al., 2023; Lonsdale et al., 2013). Secondly, the quantity, quality, and scope of physical education lessons worldwide often fail to meet the standards of "Quality Physical Education" defined by UNESCO (Goslin, 2020; UNESCO, 2014; Yuksel et al., 2020). Therefore, while physical education should remain the cornerstone of school-based physical activity, adopting complementary, comprehensive, and cost-effective approaches is recommended to effectively influence daily movement among students, especially MVPA, and promote lifelong engagement in physical activity.

Programmes implemented in the school setting aiming to improve physical activity and overall health may include one or more strategies, such as enhanced physical education, active learning and breaks, before and after school activities, and family and community engagement (Milton et al., 2021; Neil-Sztramko et al., 2021). The efficacy of such school-based interventions has yielded contradictory findings. While some studies report positive albeit modest outcomes (Mannocci et al., 2020; Nally et al., 2021; Pfledderer et al., 2021), others show inconclusive or negligible effects (Errisuriz et al., 2018; Jones et al., 2020; Love et al., 2019; Neil-Sztramko et al., 2021). Authors do agree however that comprehensive school physical activity programmes combining different intervention strategies have shown the most promising results worldwide (Klingberg et al., 2019; Neil-Sztramko et al., 2021; Pfledderer et al., 2021). Authors have also claimed that to ensure the efficacy of school-based interventions, these must be aligned with the school curriculum (van Sluijs et al., 2021) and tailored to the needs of the targeted population (Lambrinou et al., 2020).

Importantly, health-enhancing school-based interventions often fail to reach those who need them most, particularly less-active children such as those who are overweight and girls (Hartwig et al., 2021). Researchers have hence questioned whether current programmes facilitate sufficient and adequate physical activity opportunities for girls at school (Johansen et al., 2023). According to the GAPPA, efforts must be made "to engage with, and increase the opportunities for, physical activity in the least active groups… such as girls… and vulnerable or marginalized populations"

(World Health Organization, 2018, p. 37), which warrants further investigation into intervention effects among young sub-populations in vulnerable situations.

Furthermore, long-term outcome data on the effectiveness of physical activity interventions is scarce, but indicates that positive effects observed in the short-term are difficult to maintain over time (Lai et al., 2014; Nguyen et al., 2016). A major factor contributing to the attenuation of beneficial results is the discontinuation of interventions (Herlitz et al., 2020). Indeed, the sustainability of public health programmes has been recognised as a prominent challenge in translating research into practice (Shelton et al., 2018). Therefore, incorporating follow-up measures to assess the maintenance of desired outcomes and continuation of school-based physical activity and health-enhancing programmes is warranted.

1.3.3. Evaluation of school-based programmes

The exposed evidence suggests that comprehensive school-based health promotion interventions may improve health behaviours and cardiovascular outcomes among children and adolescents, but that the actual outputs of these programmes often diverge from the anticipated ones. The discrepancy in outcomes has been attributed to the intricate interplay of contextual factors present in the school settings in which interventions take place (Darlington et al., 2018). Such contextual factors encompass both internal and external conditions, including intervention characteristics, staff engagement, executive support, or system policies, and significantly influence the implementation process and subsequent outcomes of health programmes (Shoesmith et al., 2021; Wolfenden et al., 2022). Therefore, gaining a comprehensive understanding of contextual determinants is central to assess their impact on the effective implementation of health promotion programmes in educational settings. This is particularly relevant for schools of lower socioeconomic status, where challenges during programme implementation are more apparent (Darlington et al., 2018).

Implementation science

Implementation science is a relatively new field seeking to bridge this gap between research and public health practice. It is defined as “the scientific study of methods to promote the systematic uptake of… evidence-based practices into routine practice, and, hence, to improve the quality and effectiveness of health services” (Eccles & Mittman, 2006, p. 1). The rapid growth of

implementation research over the past years has given rise to a plethora of theories, models, and frameworks (Tabak et al., 2012). In turn, implementation science is operationalised through the use of implementation strategies and implementation outcomes. Implementation strategies represent a diverse range of techniques and methods employed to increase the adoption, implementation, and sustainability of programmes, interventions, or practices (Proctor, 2013). Meanwhile, implementation outcomes are measures of the extent and quality of the implementation process, and are considered the primary outcomes of implementation science (Curran, 2020). A practical taxonomy of implementation outcomes has been proposed by Proctor et al. (2011) and include the domains of acceptability, adoption, appropriateness, cost, feasibility, fidelity, penetration, and sustainability.

The use of implementation science is gaining popularity in other domains within (and outside) public health, with growing albeit still limited evidence in community settings like schools (Wolfenden et al., 2019). A Cochrane review analysing strategies that facilitate the implementation of school-based practices targeting behavioural risk factors for chronic diseases has reported substantial improvements on implementation outcomes (Wolfenden et al., 2022). In another review on NCD prevention strategies in the community, the same authors point out that while fidelity, penetration, and adoption were the most commonly reported outcomes, evidence on acceptability, feasibility, costs, and sustainability was limited (Wolfenden et al., 2019). However, the use of implementation science in the field of physical activity is still an emerging area.

The literature on school-based physical activity interventions is dominated by efficacy studies, whereas an evident gap exists linking health outcomes to programme implementation (Naylor et al., 2015). Furthermore, the available body of literature on implementation research in physical activity has thus far focused on the context of these efficacy trials. Meanwhile, evidence on implementation under real-world conditions is uncommon yet necessary to achieve population impact (Cassar et al., 2019). Another recognised shortcoming of implementation science in health promotion in general and physical activity in particular is the use of different or not validated frameworks, while many studies fail to report them altogether (Bodkin & Hakimi, 2020; Cassar et al., 2019).

Thus, to optimise NCD prevention interventions within the realities of the educational system, researchers have advocated for more extensive research on implementation utilising established

frameworks and a comprehensive array of implementation outcomes (van Sluijs et al., 2021; Wolfenden et al., 2019). Particularly during the sustainability phase, additional research is warranted to support the successful integration of school-based physical activity interventions in real-world settings, especially in LMICs and resource-limited communities, where empirical evidence remains scarce (Cassar et al., 2019; Hailemariam et al., 2019; Yapa & Barnighausen, 2018).

1.3.4. The case of South Africa

The available evidence on health promoting programmes embedded in schools in Africa is limited (Adom et al., 2019; Klingberg et al., 2019; Salam et al., 2020; van Sluijs et al., 2021), as highlighted by the representation from only one sub-Saharan African country, namely South Africa, in the umbrella review by Barbosa Filho et al. (2016) exploring physical activity promotion worldwide. Similarly, the Global Observatory for Physical Activity reported the lowest capacity for physical activity promotion in Africa (Ramirez Varela et al., 2022). Pratt et al. (2020) argue that the lack of understanding of how best to promote physical activity in LMICs is holding back the global progress in the fight against the physical inactivity pandemic.

In South Africa, the significant burden of disease and mortality inequalities emphasises the importance of addressing social determinants of health (Pillay-van Wyk et al., 2016). The national strategic plan for the prevention and control of NCDs 2013-2017 advocates the primary prevention of NCDs and their risk factors through cost-effective interventions (sub-strategy 1) (National Department of Health, 2013). The plan specifically calls for policies and actions seeking to increase physical activity "in all aspects of daily living, such as giving priority to regular and intense physical education classes in schools" (p. 69). However, the gap between policy and implementation is evident in South Africa as well. Despite documented calls to reinstate physical education as a mandatory, independent subject in the South African school curriculum, tangible progress remains elusive (Burnett, 2020; Draper et al., 2018). Consequently, strengthening physical education in schools through comprehensive programmes emerges as a crucial strategy to promote physical activity and mitigate risk factors for chronic diseases among South African youth, especially those residing in under-resourced areas (Bradshaw et al., 2007).

Health-enhancing initiatives in South African schools

Several projects have been initiated in quintiles 1 to 3 schools, denoting non-fee paying public schools (quintiles 4 to 5 represent higher-income, paying public schools), which are typically situated in low-income communities.

Walter (2014) designed an intervention focusing on low-cost environmental adaptations to prompt free play through games and basic equipment. Implemented in three peri-urban primary schools in the Gqeberha area, the intervention significantly raised children's MVPA levels during school, demonstrating that basic environmental changes might be an effective and affordable strategy to enhance physical activity in these settings.

Adding to the provision of basic materials, Naidoo and Coopoo (2012) developed classroom-based lessons aligned with the school curriculum and supported by training workshops for educators. Eleven primary schools from diverse settings in KwaZulu-Natal partook in the study, reporting a significant increase in learners' participation during physical education classes. The efficient delivery of the intervention by Life Orientation educators led the authors to recommend complementing such initiatives with workshops designed to enhance knowledge and skills among generalist teachers.

A school-based and family physical activity intervention was delivered in one experimental school in the Clemont Township of KwaZulu-Natal focusing on strengthening physical activity within the existing physical education curriculum **(**Nyawose & Naidoo, 2016). The intervention yielded positive results, with learners increasing their participation in physical education classes and teachers stating an increased confidence in its teaching.

Similarly, the Healthnutz intervention integrated physical activities and health education lessons into the Life Orientation curriculum, providing training for classroom teachers in three urban primary schools in the Alexandra Township, Johannesburg (Draper et al., 2010a). The results were promising, with both learners and teachers reporting an enhanced perceived value of physical activity in the schools, reduced barriers to its implementation, and an overall healthier school environment. Teachers emphasised the need for external support and capacity development. Furthermore, follow-up visits to the Healthnutz schools showed that the intervention was no longer being implemented as originally intended, although certain cultural changes might have endured.

This observation led Draper et al. (2010a) to highlight the importance of investigating the sustainability of future interventions.

In contrast, the low-intensity intervention HealthKick aimed at increasing nutrition and physical activity in eight historically disadvantaged schools in the Western Cape did not yield significant improvements (Draper et al., 2010b). Co-implementation schools engaged in goal-setting action planning, and received resources with lesson plans, implementation strategies, and a curriculum as well as basic equipment. However, only 25.9% of planned actions were implemented by the schools, and no improvements in determinants of physical activity were observed (de Villiers et al., 2015; Uys et al., 2016a). The authors concluded that a more structured strategy, including prescribed exercises and lessons, might be necessary to achieve results in these communities (Hill et al., 2015).

Lastly, the "Disease, activity and schoolchildren's health" (DASH) project was created to improve the health of children in impoverished areas of the Eastern Cape, with a focus on parasitic infections and physical activity (Yap et al., 2015). The intervention comprised three components: regular physical activity through curriculum-adapted physical education and dancing lessons, health education to increase hygiene and sanitation awareness, and nutritional lessons. It was found that the intervention successfully impacted adiposity measures, but not cardiorespiratory fitness (Gerber et al., 2018; Müller et al., 2019a). A positive association of physical activity with quality of life and parasitic infections was also described, indicating the need for a holistic approach to effectively improve children's overall health through school-based interventions in these areas (Gerber et al., 2018; Salvini et al., 2018).

These initiatives underscore the value of promoting physical activity in disadvantaged areas of South Africa, yet they reveal that successful implementation faces considerable challenges that demand thorough examination of contextual factors and ongoing evaluation. A systematic review on obesity prevention programmes in Africa highlighted their promising impact on physical activity but unveiled a generally low quality of the evidence and a lack of formal process evaluations (Klingberg et al., 2019). Among the aforementioned South African initiatives, the HealthKick intervention stands out for conducting a comprehensive process evaluation (de Villiers et al., 2012; de Villiers et al., 2015; Hill et al., 2015; Uys et al., 2016a), although not guided by a theoretical framework (Draper et al., 2010b). In line with the findings of the Healthy Active Kids

Report South Africa 2016, there is a need for more robust study designs to assess the effectiveness of existing school-based health and physical activity programmes in the country, along with comprehensive process evaluations (Uys et al., 2016b).

1.4. The *KaziKidz* intervention

Building on previous physical activity and health-enhancing programmes in South African schools from disadvantaged communities, particularly the DASH study (Yap et al., 2015), the *KaziBantu* project "Healthy Schools for Healthy Communities" was developed under the umbrella of the UNESCO Chair on "Physical Activity and Health in Educational Settings" (Müller et al., 2019b). The project's overarching aim is to improve health and well-being in these communities of learners and teachers by fostering physical and health literacy, aligning with SDG3 "Good Health and Wellbeing" and 4 "Quality Education" (United Nations, 2015a, 2015b).

The *KaziBantu* project was introduced in peri-urban areas surrounding the city of Gqeberha, situated in the Nelson Mandela Bay Municipality of the Eastern Cape province of South Africa. These areas represent townships, which are historically disadvantaged communities designated during the apartheid era for occupation by people of colour and purposefully segregated from urban centres (Donaldson, 2014). The enduring impact of this unique historical background on the development of townships has resulted in their persistent marginalisation, with spatial, social, economic, and political exclusion still prevalent to this day. As a result, these areas continue to suffer from significant hardship, including high levels of poverty, inadequate housing, unemployment, crime, and limited educational opportunities (Jürgens et al., 2013).

The novelty and significance of *KaziBantu* lie in its dual approach, whereby two different but complementary programmes were designed to address the needs of both school learners and their teachers. On the one hand, *KaziHealth* is a workplace intervention grounded on a behavioural change model, seeking to promote healthier choices, enhanced physical activity, better nutrition, and improved psychosocial health for teachers. As a 5-step programme, it begins with a health assessment to identify risk areas, followed by lifestyle coaching to improve health behaviours and supported by freely available resources to monitor progress including the *KaziHealth* mobile application. On the other hand, *KaziKidz* focuses on children's health and involves a multi-component intervention targeting various aspects of health and physical activity in schools. Its primary objective is to support Life Skills and Life Orientation teachers in delivering high quality,

comprehensive physical and health education to foster physically active and health-promoting lifestyles among learners.

The *KaziKidz* programme encompasses a teachers' toolkit with readily available lessons covering three main pillars: physical education, moving to music, and health, hygiene, and nutrition education. These lessons align with the current Life Skills and Life Orientation curriculum for grades 1 to 7 and are delivered once a week throughout the scholar year. Emphasising joyful participation in physical activities through games and fun, the lessons are complemented with small environmental changes including painted games on the playground, such as hopscotch, 4-square, or mazes, as well as the facilitation of basic physical activity equipment like skipping ropes, balls, bean bags, and others.

KaziKidz was initially piloted in two primary schools in 2018, and teachers' feedback was used for material revision. In 2019, *KaziKidz* was implemented as a clustered randomised controlled trial (RCT) in eight quintile 3 public primary schools, with four schools receiving the teaching materials and delivering the intervention, while another four schools acted as control. Furthermore, the study design was devised to simultaneously test and compare four different implementation strategies. In addition to the *KaziKidz* toolkit, the intervention schools received diverse types of support from the research team. Specifically, one school engaged in two training workshops for generalist teachers, another school received coaching from a physical education coach, and a third school had both forms of support. The fourth school did not receive any additional assistance. The *KaziKidz* intervention spanned a 20-week period, with two rounds of data assessments carried out at baseline in January to February 2019 and post-intervention in August to September 2019. The intervention's efficacy was evaluated as its impact on diverse health outcomes, including physical activity, physical fitness, anthropometric measures, cardiometabolic risk markers, psychosocial health, and cognitive and academic performance.

After concluding the RCT, a follow-up mixed-methods study was initiated in 2020 to assess the continuity of the *KaziKidz* programme in participating schools and its sustained effectiveness among a sub-group of high-risk children, during the programme's sustainability phase. To achieve this goal, both quantitative and qualitative data were gathered in October 2021, two years after the intervention. This data included health outcomes related to physical activity and cardiometabolic

parameters for children at risk of NCDs as well as semi-structured and focus group interviews with key stakeholders from the intervention schools.

The study design encompassing both the implementation and sustainability phases of *KaziKidz* is visually represented in Figure 2.

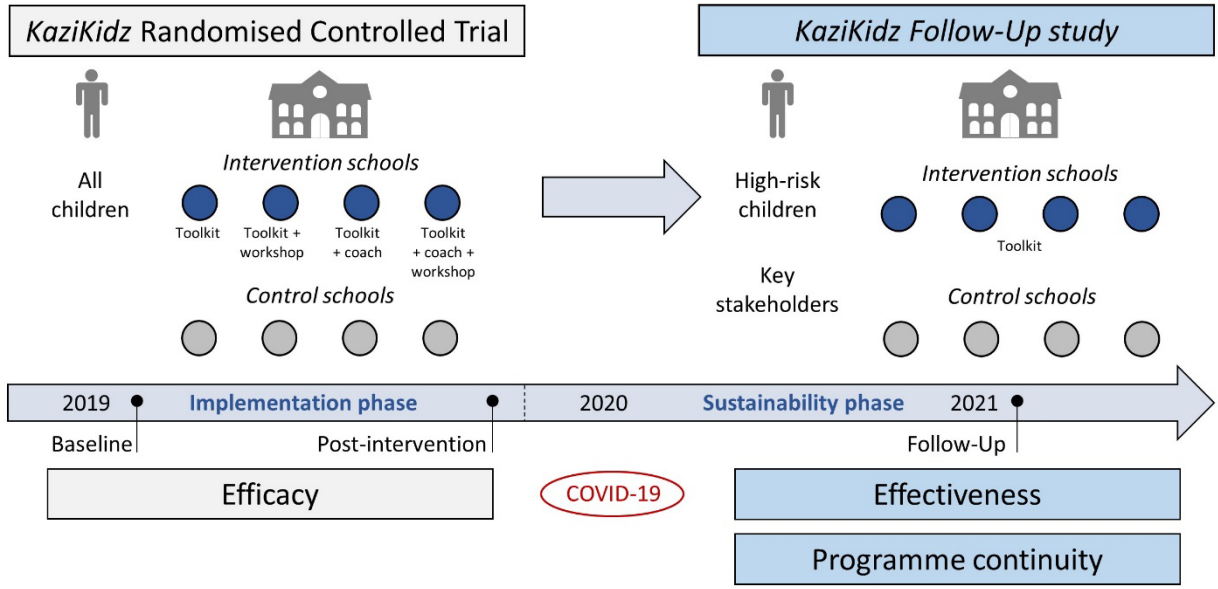

Figure 2. Study design of the *KaziKidz* health and physical activity intervention implemented in eight public primary schools near Gqeberha, South Africa, between 2019 and 2021.

Chapter 2. Aims and outline of the thesis

Chapter 1 has introduced the theoretical background and situational analysis on NCDs and physical activity as well as strategies to encourage the role of the latter in health promotion and disease prevention, taking a particular emphasis on both children and the South African context.

In front of the background provided in Chapter 1, the following section summarises research gaps identified in the literature that are relevant to the primary goal of this PhD thesis, the comprehensive evaluation of the *KaziKidz* health promotion intervention during its sustainability phase. The specific aims are then formulated based on the identified knowledge gaps, followed by an overview of the steps taken to achieve the described objectives.

2.1. Knowledge gaps

Firstly, uniform, comparable, and representative data on NCDs and physical activity is essential to make informed policy decisions regarding the monitoring and control of risk factors for NCDs (Ndinda et al., 2018). However, the scarcity of evidence on early risk factors in children from low-resourced settings is exacerbated by the lack of representation and harmonisation in the definition, measurement, and identification of CVD risk factors, particularly hypertension and physical activity (Pedisic & Bauman, 2015; Stavnsbo et al., 2018). Therefore, to evaluate the efficacy of preventive interventions in improving determinants of chronic disease, it is necessary to understand which constructs and methodologies are most suitable for identifying risk in the targeted population. There is hence a need to explore the appropriateness of normative blood pressure tables and physical activity measurement instruments in detecting elevated cardiovascular risk among South African school-aged children.

Secondly, school-based programmes represent a promising strategy to curb the escalating burden of NCD risk factors among children and adolescents. Nevertheless, conflicting results have emerged regarding their potential to achieve positive outcomes, with the majority of evidence originating from HICs (Barbosa Filho et al., 2016; Neil-Sztramko et al., 2021). Moreover, research also denotes that the impact of physical activity programmes conducted in schools might not be equal across all children, with less active groups often experiencing fewer benefits (Hartwig et al., 2021). Importantly, children exhibiting a severe expression of common risk factors are particularly vulnerable to adverse health outcomes (de Ferranti et al., 2019). Thus, further research on the

efficacy of physical activity and health interventions is warranted to shed light on inconsistencies found in the literature, especially among children living in socioeconomically disadvantaged settings and presenting an elevated risk for NCDs.

Thirdly, the success of school-based interventions in improving health outcomes depends not only on the intervention itself but also on its implementation. Evidence-based interventions are introduced into complex systems. Here, aspects such as the acceptance by key stakeholders or the viability to conduct the programme can impact their effective uptake and deployment, consequently affecting their short- and long-term effectiveness (Darlington et al., 2018; Wolfenden et al., 2022). Despite its importance, the study of implementation outcomes in physical activity promotion remains a developing field, with a particular dearth of evidence from LMICs regarding the adoption, implementation, and sustainability of school-based physical activity interventions (Cassar et al., 2019; Wolfenden et al., 2019). Hence, it becomes imperative to evaluate the contextual factors influencing the implementation of health promoting initiatives in South African schools. This will allow drawing meaningful conclusions about the intervention's potential to produce the expected effects.

Fourthly, the existing literature reveals that most school-based programmes cease or deviate from their intended course after the intervention period, resulting in a regression of improvements achieved (Herlitz et al., 2020; McEwan et al., 2020). Yet, there is a noticeable lack of research examining the long-term effectiveness and continuity of health enhancing programmes in schools (Cassar et al., 2019; Nguyen et al., 2016). The evaluation of programme sustainability becomes particularly crucial in LMICs, where scarce funding and dependence on external financial aid may impact intervention maintenance (Herlitz et al., 2020). Furthermore, understanding the sustainability of an intervention is complex, requiring a holistic approach and the use of well-established methodologies (Shelton et al., 2018). Therefore, studying the maintenance of health outcomes and the sustainment of interventions under real-world conditions, especially in low-income settings, is essential and best informed by implementation science.

2.2. Aims and hypotheses

This thesis encompasses four study aims formulated in line with the identified knowledge gaps.

Study aim 1: Risk identification

The first aim was to assess the suitability of established methodologies in identifying cardiovascular risk among school-aged children residing in economically disadvantaged areas in Gqeberha, South Africa. The aim was two-fold:

Study aim 1.a. sought to compare four different blood pressure references and ascertain their potential in determining paediatric hypertension and associated risk for increased BMI-for-age and isolated systolic hypertension.

Study aim 1.b. aimed to compare self-reported with device-measured physical activity as well as analyse their respective association with cardiometabolic risk markers, including BMI, blood pressure, serum lipids, and plasma glucose.

Hypothesis 1

It was hypothesised that different blood pressure references and physical activity assessment methodologies would yield inconsistent results concerning estimations of paediatric hypertension and physical activity levels, respectively. It was further hypothesised that diverse physical activity constructs measured via self-reports and wearable devices would vary in their potential to predict cardiometabolic risk.

Study aim 2: Intervention outcomes

The second aim was to evaluate the impact of the *KaziKidz* intervention on physical activity levels and cardiometabolic parameters among children with an increased risk for NCDs. The aim was two-fold:

Study aim 2.a. aimed to examine the intervention's efficacy by analysing the short-term effects on MVPA as well as BMI-for-age, mean arterial pressure, total cholesterol (TC) to high-density lipoprotein (HDL) ratio, and HbA1c of children at risk and not at risk.

Study aim 2.b. aimed to investigate the long-term effectiveness of the intervention by assessing the development of said health outcomes among at-risk children two years' post-intervention.

Hypothesis 2

Compared to both a control group and healthy counterparts, it was hypothesised that *KaziKidz* would have a positive impact on physical activity levels and cardiometabolic risk factors among high-risk children, but that potential short-term benefits would decline over time.

Study aim 3: Implementation outcomes

The third aim was to explore contextual factors that could have influenced the adoption and implementation of the *KaziKidz* intervention, as reported by school personnel and caregivers, as well as to provide recommendations for its future development and dissemination. The aim was three-fold:

Study aim 3.a. sought to gain a better understanding of the acceptability of the programme by assessing how the intervention was received by those involved and their perspectives on its relevance.

Study aim 3.b. aimed to offer insights into the perceived feasibility of the intervention by exploring stakeholder's experiences, that is to say facilities and difficulties, during its implementation.

Study aim 3.c. sought to identify practical challenges and opportunities related both to the intervention and its implementation, and to propose strategies to enhance its effectiveness.

Hypothesis 3

Previous studies in the area have elucidated barriers and facilitators of school-based interventions, so it was hypothesised that the *KaziKidz* intervention would generally be well-received and feasible, while certain obstacles might have hindered its successful implementation.

Study aim 4: Sustainability assessment

The fourth aim was to evaluate the sustainability of the *KaziKidz* intervention in terms of its continuation in schools and its impact on the maintenance of positive health outcomes in children.

Hypothesis 4

Given the emergence of the COVID-19 pandemic shortly after the conclusion of the intervention and its ongoing status during the current evaluation, it was anticipated that the state-mandate temporary closure of education institutions would significantly affect the programme's

sustainment in the participating schools, even though obstacles to its continuation would be expected under normal circumstances as well.

2.3. Outline

The structure of this PhD thesis is given by the steps undertaken to cover the elucidated aims and encompasses five publications.

Step 1

The present evaluation of the *KaziKidz* intervention is focused on its impact on children at higher risk for NCDs, that is, those presenting one or more cardiometabolic risk factor. For that purpose, it was necessary to determine the reliability of various methodologies in detecting increased risk within the specific study population. Thus, to identify the study population at risk and according to aim 1.a., publication 1 first compared four international, national, and local blood pressure references to establish the most appropriate way of ascertaining hypertension among South African school-aged children. In alignment with aim 1.b., publication 2 then investigated two physical activity measurement methods, self-report using the Physical Activity Questionnaire for Children (PAQ-C) and device-based using accelerometry, in their association with CVD outcomes.

Step 2

The protocol of the mixed-methods follow-up study conducted subsequent to the RCT in 2019 and involving the evaluation of the *KaziKidz* intervention during the sustainability phase was published (publication 3). The protocol provides detailed insights into the rationale of the study, study design, setting, participant recruitment, test battery, data collection, measurement instruments, and data analysis. The evaluation is grounded on the RE-AIM framework (Reach, Effectiveness, Adoption, Implementation, Maintenance), a well-established implementation science model for assessing public health programmes (Glasgow, 1999; Nilsen, 2015). Numerous studies showcase the application of RE-AIM in school-based health interventions, including physical activity promotion, demonstrating a flexible use of the framework to suit the intervention's requirements and researchers' priorities (Christian et al., 2020; da Silva Bandeira et al., 2022; Kennedy et al., 2021; Lewis et al., 2017; McGoey et al., 2015). This dissertation focuses on key dimensions relevant to the *KaziKidz* intervention, that is efficacy and effectiveness, acceptability to inform adoption, feasibility to inform implementation, and sustainability to inform maintenance.

Considering recent recommendations to incorporate mixed-method approaches to explore RE-AIM dimensions (Glasgow et al., 2019), this dissertation employs a mixed methods convergent design proposed by Creswell and Plano Clark (2017), as depicted in Figure 3. The mixed-methods convergent design entails first a separate summary and interpretation of each outcome, followed by a subsequent discussion on how the results from both types of data relate to each other.

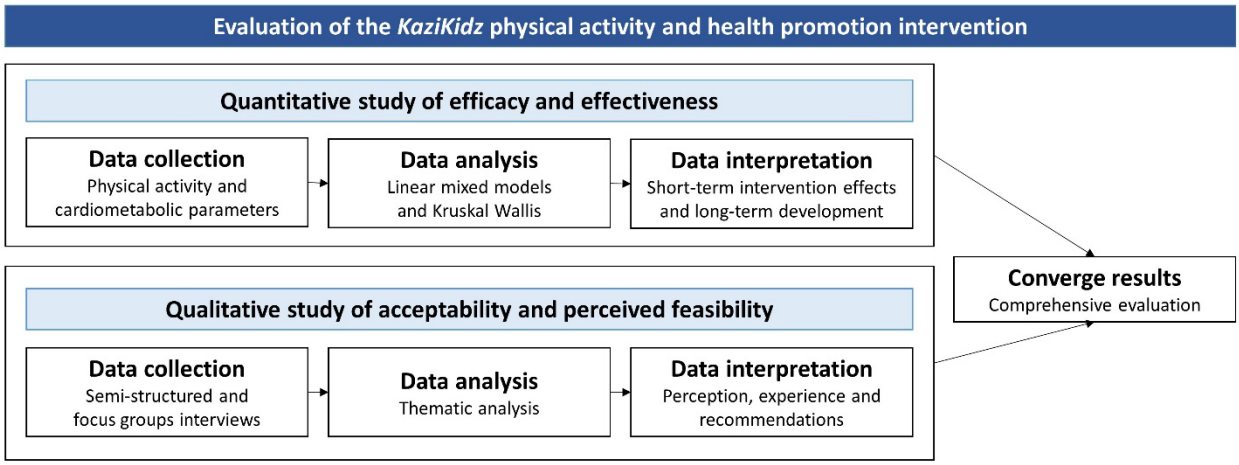

Figure 3. Mixed-methods convergent design for the evaluation of the *KaziKidz* intervention during its sustainability phase, adapted from Creswell and Plano Clark (2017).

Step 3

The first step in the evaluation was the assessment of the intervention's short-term impact on the desired health outcomes. Therefore, according to aim 2.a., publication 4 analysed the efficacy of the *KaziKidz* intervention in the context of the RCT conducted in 2019. Specifically, the intervention's effects on physical activity levels and cardiometabolic outcomes were compared before and after the intervention's implementation between children at risk of NCDs and their healthy counterparts in both the control and intervention groups.

Step 4

Following, contextual factors pertaining to both the *KaziKidz* programme and the schools and their potential influence on intervention success were examined. To achieve this, a nested qualitative study was conducted with school principals, teachers, and caregivers as part of the follow-up evaluation to gain insights into their attitudes towards the programme and their experiences implementing it in the schools. Aligning with aim 3, publication 5 explored the acceptability and

perceived feasibility of school personnel and caregivers to gain a better understanding on how these might have influenced the adoption, support, delivery, and maintenance of the intervention.

Step 5

Lastly, in accordance with aim 4, the sustainability of the *KaziKidz* programme two years after its conclusion was investigated. For that purpose, the development of health outcomes over time was analysed. According to aim 2.b., publication 4 examined the long-term maintenance of physical activity and cardiometabolic parameter levels focusing on children with an adverse cardiovascular profile at baseline. Subsequently, the ongoing implementation of *KaziKidz* in the participating schools was to be assessed. However, the unforeseen breakout of the COVID-19 pandemic and the following lockdown measures disrupted the programme's sustainment. Instead, a comprehensive analysis of the observed long-term outcomes in light of the COVID-19 pandemic will be presented in the discussion section of this thesis, together with potential scenarios for the continuity of *KaziKidz* taking into account insights from the qualitative findings.

A summarised version of the outline of the thesis is provided in Table 1, referring to each step and its corresponding aim and relevant publication.

Table 1. PhD thesis outline.

Steps	**Aims**	**Publications**
Step 1	Aim 1.a. Hypertension identification	Publication 1
	Aim 1.b. Physical activity and cardiovascular risk	Publication 2
Step 2	Study protocol	Publication 3
Step 3	Aim 2.a. Intervention efficacy	Publication 4
Step 4	Aim 3.a. Acceptability	Publication 5
	Aim 3.b. Perceived feasibility	
Step 5	Aim 2.b. Long-term intervention effectiveness	Publication 4
	Aim 4. Sustainability	PhD thesis

Chapter 3. Publication 1

Practice Change Needed for the Identification of Pediatric Hypertension in Marginalized Populations: An Example From South Africa

Patricia Arnaiz[1], Ivan Müller[1], Harald Seelig[1], Markus Gerber[1], Jacob Bosma[2], Danielle Dolley[2], Larissa Adams[2], Jan Degen[1], Stefanie Gall[1], Nandi Joubert[1,3,4], Madeleine Nienaber[2], Siphesihle Nqweniso[2], Ann Aerts[5], Peter Steinmann[3,4], Rosa du Randt[2], Cheryl Walter[2], Jürg Utzinger[3,4], Uwe Pühse[1]

[1]Department of Sport, Exercise and Health, University of Basel, 4052 Basel, Switzerland.

[2]Department of Human Movement Science, Nelson Mandela University, 6031 Gqeberha*, South Africa.

[3]Swiss Tropical and Public Health Institute, 4002 Basel, Switzerland.

[4]University of Basel, 4001 Basel, Switzerland.

[5]Novartis Foundation, Basel, Switzerland.

Published in:

Frontiers in Pediatrics. 2022; 10:877431.

The final publication is available at: https://doi.org/10.3389/fped.2022.877431.

frontiers | Frontiers in Pediatrics

ORIGINAL RESEARCH
published: 11 May 2022
doi: 10.3389/fped.2022.877431

Practice Change Needed for the Identification of Pediatric Hypertension in Marginalized Populations: An Example From South Africa

Patricia Arnaiz[1], Ivan Müller[1], Harald Seelig[1], Markus Gerber[1], Jacob Bosma[2], Danielle Dolley[2], Larissa Adams[2], Jan Degen[1], Stefanie Gall[1], Nandi Joubert[1,3,4], Madeleine Nienaber[2], Siphesihle Nqweniso[2], Ann Aerts[5], Peter Steinmann[3,4], Rosa du Randt[2], Cheryl Walter[2], Jürg Utzinger[3,4] and Uwe Pühse[1]*

[1] Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland, [2] Department of Human Movement Science, Nelson Mandela University, Gqeberha, South Africa, [3] Swiss Tropical and Public Health Institute, Allschwil, Switzerland, [4] University of Basel, Basel, Switzerland, [5] Novartis Foundation, Basel, Switzerland

OPEN ACCESS

Edited by:
Alessandro Giamberti, IRCCS San Donato Polyclinic, Italy

Reviewed by:
Paolo Ferrero, IRCCS San Donato Polyclinic, Italy
Aftab S. Chishti, University of Kentucky, United States

***Correspondence:**
Patricia Arnaiz
patricia.arnaiz@unibas.ch

Specialty section:
This article was submitted to Pediatric Cardiology, a section of the journal Frontiers in Pediatrics

Received: *16 February 2022*
Accepted: *18 April 2022*
Published: *11 May 2022*

Citation:
Arnaiz P, Müller I, Seelig H, Gerber M, Bosma J, Dolley D, Adams L, Degen J, Gall S, Joubert N, Nienaber M, Nqweniso S, Aerts A, Steinmann P, Randt Rd, Walter C, Utzinger J and Pühse U (2022) Practice Change Needed for the Identification of Pediatric Hypertension in Marginalized Populations: An Example From South Africa. Front. Pediatr. 10:877431. doi: 10.3389/fped.2022.877431

Introduction: Hypertension in children has increased globally over the past 20 years; yet, little is known about this issue among disadvantaged communities from low- and middle-income countries. Age-, sex-, and height-adjusted normative tables are the "gold" standard for the diagnosis and estimation of pediatric hypertension worldwide, but it is unclear whether the use of international standards is appropriate for all contexts. The purpose of this study was to evaluate and compare different international references to identify hypertension among South African school-aged children from disadvantaged communities.

Methods: Blood pressure, weight, and height were measured in a cohort of 897 children aged 8–16 years from eight peri-urban schools in the Eastern Cape of South Africa. Cross-sectional prevalence of hypertension was calculated according to American, German, and global normative tables, as well as pseudo-normative data from the own study population. Isolated systolic hypertension and body mass index (BMI) were considered markers for cardiovascular disease. Multinomial logistic regression was used to compare the likelihood of blood pressure categorization with increasing BMI levels.

Results: Hypertension prevalence ranged from 11.4% with the pseudo-normative study tables to 28.8% based on the German reference. Global guidelines showed the highest agreement both among international standards (92.5% with American guidelines) and with the study reference (72.5%). While the global and the American references presented higher systolic over diastolic hypertension rates (23.6 vs. 10.6% and 24.2 vs. 14.7%, respectively), the American guidelines predicted the highest increased risk for hypertension stage 2 [odds ratio, 1.72 (95% confidence interval: 1.43–2.07)] with raising levels of BMI.

Conclusion: Our results support the heterogeneity of blood pressure estimates found in the South African literature, and highlight the underrepresentation of African children in international guidelines. We call for caution in the use of international standards in different contexts and advocate for the development of normative tables that are representative of the South African pediatric population necessary to ensure an accurate identification of hypertension both from the clinical and epidemiological perspective.

Keywords: pediatric hypertension, prevalence, identification, normative blood pressure tables, international guidelines, marginalized settings, Africa

INTRODUCTION

Cardiovascular disease (CVD) is the leading cause of mortality worldwide, accounting for over 17 million deaths yearly (1). Among the most prominent risk factors for CVD is early vascular aging, characterized by arterial stiffness (arteriosclerosis) (2). There is extensive evidence that risk factors for CVD occur early in life, causing premature organ damage that tracks into adulthood (3). In fact, arterial stiffness has been observed and related to hypertension in children (4). Hence, early detection of asymptomatic vascular changes such as elevated blood pressure (BP) is essential for effective intervention and prevention of health consequences in older ages.

However, pediatric hypertension has received little attention, especially in low- and middle-income countries (LMICs). As new research emerges, we are gaining awareness of the extent of a long underappreciated problem and the consequences of its (mis)management, such as impaired development, economic burden, years of life lost, etc. (5). A recent meta-analysis revealed that global hypertension rates among children have increased about 75% over the past 20 years (6), which has been partially attributed to the steep escalation in childhood obesity, an early-life risk factor for CVD. A similar trend for childhood hypertension is expected in African countries, where "the number of overweight children under 5 has increased by nearly 24 percent since 2000" (7). The strong association between body mass index (BMI) and BP in children has been established both globally (8) and in South Africa (9), where their relation with arterial stiffness (10) and the tracking of BP from childhood into late adolescence have been described (11). This emphasizes the need to rely on accurate estimates to monitor childhood hypertension progress and react to long-term health impacts, especially in marginalized settings, to inform policy making and ensure meaningful allocation of scarce resources (12). Despite this new knowledge, global attention and prevention efforts are still focused on high-income countries (HICs), while vulnerable populations in LMICs are often neglected.

Several guidelines have established the definition of pediatric hypertension based on normative BP tables that account for age, sex, and height, and settled abnormally elevated BP levels in children at the 90th percentile and hypertension at the 95th percentile (13, 14). Currently, the most widely used guidelines were developed by the American Academy of Pediatrics (AAP) and include normative charts based on normal-weight American children and revised cut-off points (15). However, other efforts to establish BP reference tables have been made. In Germany, reference charts were derived from a population of non-overweight children participating in the KiGGS study, and are broadly used in the literature, as well (16). Xi et al. pooled data from 7 different countries in an attempt to develop universal BP references for children (17). Notwithstanding, no normative tables exist for African children, and these populations have been underrepresented in attempts to develop global references.

Furthermore, it is unclear whether country-specific BP reference tables and uniform international standards are appropriate for the estimation of pediatric hypertension prevalence in different contexts (18). Whereas the percentile values differ between the reference populations used to calculate them, context-specific socioeconomic and environmental factors might make the broad use of such standards unsuitable. Accordingly, studies have shown low consistency between international and local normative tables (19). Indeed, the prevalence of pediatric elevated BP in the African literature varies substantially, and South African studies present conflicting results (8). Different normative data and cut-offs to define high BP are used in these studies, and it remains unclear whether some authors have developed age-, sex-, and height-specific BP reference values based on their own study population, similar to the example from the Gambian study of Modou et al. (20).

Against this background, the current study aims to examine the hypertension prevalence in 897 children from lower-income families in the Eastern Cape province of South Africa considering four different BP references. Subsequently, these BP standards are compared based on their association with increasing BMI-for-age levels, an indicator of poorer cardiovascular health. We hypothesize that international normative tables and charts developed from the same study population will yield different estimates of hypertension prevalence and a different risk profile associated with BMI-for-age among children from marginalized communities in South Africa.

MATERIALS AND METHODS

Study Population

Results are based on cross-sectional analyzes of the *KaziBantu* project cohort baseline assessment, which took place between January and March 2019 (21). Children aged 8–16 years were recruited from eight schools from the economically disadvantaged peri-urban townships and northern areas of Gqeberha, South Africa. All study sites consisted of non-fee

paying, quintile 3 schools (South African schools are ranked from quintile one, the poorest, to quintile five, the least poor). In total, 975 children were enrolled in the *KaziBantu* study. Of those, 897 children (449 boys, 448 girls) presented with complete data records, after excluding those participants with missing data for sex ($n = 8$), age ($n = 9$), height ($n = 47$), weight ($n = 57$), and BP ($n = 31$).

Assessment of Blood Pressure

BP was measured three times on the upper left arm after a seated period of 5 min and with a 1-min rest between readings. A validated, automated oscillometric device (Omron®M6AC; Hoofddorp, Netherlands) and a child appropriate cuff, sized 17–22 cm, were used. Systolic and diastolic BP values were calculated as the mean of the last two readings to avoid overestimation usually observed on the first run.

Classification of Blood Pressure

Sex-, age-, and height-adjusted normative tables for pediatric BP were used to calculate systolic BP (SBP) and diastolic BP (DBP) percentiles. The following three widely recognized normative data charts were applied by running the programs indicated by each author: (i) AAP 2017 based on an American reference population (15, 22), (ii) Robert Koch-Institute based on a German reference population (16), and (iii) an international reference based on data pooled from 7 countries (China, India, Iran, Korea, Poland, Tunisia, and USA) (17). Furthermore, a fourth reference derived from normal-weight children from the *KaziBantu* study population was used (21). Because the study sample is classified through its own constructed normative tables, the study reference will henceforth be considered pseudo-normative. Details of the reference populations are presented in **Supplementary Table S1**.

Thereafter, the obtained percentiles were classified as normotension, elevated BP or hypertension stages 1 and 2, for both SBP and DBP, based on the cut-offs suggested in each reference, with the exception of the 99th + 5 mm Hg percentile recommended by Neuhauser et al. for stage 2 hypertension, where we applied a comparable cut-off at the 99.75th percentile to facilitate analysis. The highest value of either SBP or DBP was allocated to determine combined BP.

Anthropometric Parameters

Body weight was measured on a digital weighing scale; children were barefoot and wore school uniform. Body height was measured against a stadiometer; children were asked to stand still with their back erect and shoulders relaxed. BMI was calculated from both weight and height according to weight (kg)/height $(m)^2$. BMI-for-age Z-scores (BAZ) stratified by sex, a measure for obesity, overweight and thinness, were determined according to World Health Organization's (WHO) growth charts (23).

Statistical Analysis

Descriptive statistics for all variables comprised means (M) and standard deviation (SD). Differences between the means for boys and girls were analyzed via independent *t*-tests for significance and Cohen's d for effect size. Polynomial regressions were used to construct pseudo-normative tables from the *KaziBantu* study population after removing outlying participants and those children whose BMI was higher than 1 SD above the group average. SBP and DBP pseudo-normative charts for boys and girls are available in the **Supplementary Table S2**. Prevalence of BP categorization is expressed as frequencies (N) and percentages (%) for all four classification standards. Pearson chi-square (χ^2) tests were carried out to assess the distribution of sex (girls and boys) and age ($\leq$10, 10, 11, $\geq$11 years) in all BP categories for SBP, DBP, and BP combined. Multinomial logistic regression analyzes were used to explore the association of increasing BAZ values with the prediction of BP classification into higher categories.

Statistical tests were performed using IBM SPSS version 26 (IBM; Armonk, New York, USA). Normative BP tables were applied in STATA version 15.1 (StataCorp; College Station, Texas, USA) for the German reference population and in SAS version 9.4 (SAS Institute; Cary, North Carolina, USA) for the American and global references. BP percentile tables of the *KaziBantu* study population were constructed in Statistica version 13 (TIBCO Software Inc., Palo Alto, USA).

RESULTS

Descriptive Statistics

Table 1 presents descriptive statistics and characteristics of the study participants, stratified by sex. Girls showed a statistically significant lower mean age (10.2 vs. 10.6 years; $p < 0.001$), while presenting higher mean values for the other variables. Differences in weight (36.7 vs. 34.5 kg), BMI (18.4 vs. 17.5 kg/m^2), and BAZ (0.2 vs. 0.0) were of statistical significance at the $p < 0.001$ level. However, the Cohen's effect size was small for all sex differences in age ($d = 0.30$), weight ($d = 0.22$), BMI ($d = 0.25$), and BAZ ($d = 0.21$).

Hypertension Prevalence

We classified BP levels according to the four normative charts and their corresponding cut-offs (**Table 2**). Similar combined hypertension prevalence was observed for the three international references, namely 28.6% based on the American, 28.8% on the German, and 25.6% on the global. In contrast, only 11.4% of children were identified as hypertensive according to the pseudo-normative study reference. The highest level of agreement was found between the American and the global references with 92.5%, whereby 830 children were equally stratified throughout all four categories. The *KaziBantu* classification revealed the highest agreement percentage with the global reference (71.5%) (data not shown).

Sub-analyzes showed that the biggest disagreement between the study reference and international guidelines lied in the classification of SBP. While hypertension was more than three times higher for SBP with the American classification compared to *KaziBantu*'s (24.2 vs. 7.2%), it was almost double for DBP (14.7 vs. 7.7%). Thus, the main driver for hypertension when applying the American guidelines was SBP rather than DBP. The higher systolic over diastolic hypertension prevalence was also observed with the global reference (23.6% for SBP vs. 10.6% for DBP).

TABLE 1 | Participant characteristics and comparison between South African girls and boys from the *KaziBantu* study population in Gqeberha, South Africa.

Parameter	Total ($N = 897$) M (SD)	Boys ($N = 449$) M (SD)	Girls ($N = 448$) M (SD)	*t*	Cohen's d
Age (years)	10.4 (1.2)	10.6 (1.2)	10.2 (1.1)	4.48***	0.30
SBP* (mm Hg)	108.9 (13.4)	108.6 (13.1)	109.3 (13.7)	−0.86	0.06
DBP† (mm Hg)	67.2 (10.9)	66.5 (11.0)	67.8 (10.8)	−1.74	0.12
Height (cm)	139.9 (8.8)	139.6 (8.7)	140.2 (9.0)	−1.02	0.07
Weight (kg)	35.6 (10.2)	34.5 (9.2)	36.7 (11.0)	−3.29***	0.22
BMI‡ (kg/m^2)	18.0 (3.7)	17.5 (3.3)	18.4 (4.0)	−3.74***	0.25
BMI-for-age Z-scores	0.1 (1.3)	−0.04 (1.3)	0.2 (1.3)	−3.19***	0.21

**Systolic blood pressure.*
† Diastolic blood pressure.
‡Body mass index.
****$p < 0.001$.*
Cohen's d effect size: $d < 0.2$: no effect; $0.2 \leq d < 0.5$: small effect; $0.5 \leq d < 0.8$: medium effect; $d \geq 0.8$: large effect.

TABLE 2 | Comparison of high blood pressure prevalence among school-aged children in Gqeberha, South Africa, in July 2019 according to the (i) American Academic of Pediatrics, (ii) German guidelines, (iii) a global reference population, and (iv) the *KaziBantu* study population ($N = 897$).

References	Normal blood pressure	Elevated blood pressure	Hypertension stage 1	Hypertension stage 2
Flynn et al. (15)*	555 (61.9%)	85 (9.5%)	181 (20.2%)	76 (8.5%)
Neuhauser et al. (16)†	572 (63.8%)	65 (7.2%)	163 (18.2%)	97 (10.8%)
Xi et al. (17)‡	565 (63.0%)	102 (11.4%)	159 (17.7%)	71 (7.9%)
Müller et al. (21)§	738 (82.3%)	57 (6.4%)	65 (7.2%)	37 (4.1%)

**Normotension: <13 years old: <90th; >13 years old BP < 120/80 mm Hg; elevated BP: <13 years old: ≥90th and <95th or >120/80 mm Hg but <95th; >13 years old: 120/<80 to 129/<80 mm Hg; HTN stage 1: <13 years old: ≥95th and <95th + 12 mm Hg or 130/80–139/89 mm Hg; >13 years old: 130/80 mm Hg to 139/89 mm Hg; HTN stage 2: <13 years old: ≥95th + 12 mm Hg or ≥140/90 mm Hg; >13 years old: ≥140/90 mm Hg.*
† Normotension: <90th; elevated BP: ≥90th and <95th; HTN stage 1: ≥95th and <99.75th; HTN stage 2: ≥99.75th or ≥140/90 mmHg.
‡Normotension: <90th; elevated BP: ≥90th and <95th or >120/80 mm Hg but <95th; HTN stage 1: ≥95th and <99th + 5 mm Hg; HTN stage 2: ≥99th + 5 mm Hg.
§Normotension: <90th; elevated BP: ≥90th and <95th; HTN stage 1: ≥95th and <95th+12 mm Hg; HTN stage 2: ≥95th + 12 mm Hg.

All four standards showed similar distributions between girls and boys regardless of systolic, diastolic, or combined BP. Only in the American reference, a significant association between sex and DBP classification was observed [$\chi^2_{(3)} = 10.46$, $p = 0.015$], whereby girls were disproportionately associated with hypertension stage 1 (64.6%) at the $p = 0.05$ significance level. Age showed no association with SBP, DBP, or combined BP categorization for any of the references. Sub-analyzes can be found in the **Supplementary Tables S3–S5**.

Reference Populations Comparison Based on BMI-For-Age

The association between being classified as hypertensive with higher BMI levels for all studied references is illustrated in **Figure 1**. All four standards showed a significant increased risk for being categorized as having elevated BP, hypertension stage 1, and hypertension stage 2 per standard deviation increase in BMI-for-age relative to the normotensive group. The highest odds for hypertension stage 2 with increasing BAZ was seen with the American guidelines with a 72% increased risk (95% CI: 1.43–2.07; $p < 0.001$), followed by a 65% increased risk with both the global (95% CI: 1.37–1.99; $p < 0.001$) and German references (95% CI: 1.40–1.95; $p < 0.001$). The lowest odds were found with the pseudo-normative *KaziBantu* reference at 51% (95% CI: 1.18–1.92; $p < 0.001$). The increased risk for hypertension stage 1 with increasing BAZ was similar across the American, global, and *KaziBantu* study references at ∼45%, being lowest with the German classification (OR = 1.37; 95% CI: 1.20–1.57; $p < 0.001$). Further sub-analyzes are shown in **Supplementary Table S6**. A significant increased risk of 43% ($p = 0.003$) per unit increase in BAZ was found between elevated BP and hypertension stage 2 for the American reference. With the German guidelines, increased categorization risk was significant between elevated BP and hypertension stage 2 (OR = 1.31, $p = 0.027$), and between hypertension stage 1 and hypertension stage 2 (OR = 1.20, $p = 0.05$). No significant differences were observed for the global and *KaziBantu* references.

DISCUSSION

This study demonstrates differences in the implementation of international standards for the classification of BP in diverse contexts. Among school-aged children from disadvantaged communities in the Eastern Cape Province of South Africa, the obtained prevalence of hypertension ranged from 11.4%, when pseudo-normative tables from the own study population were

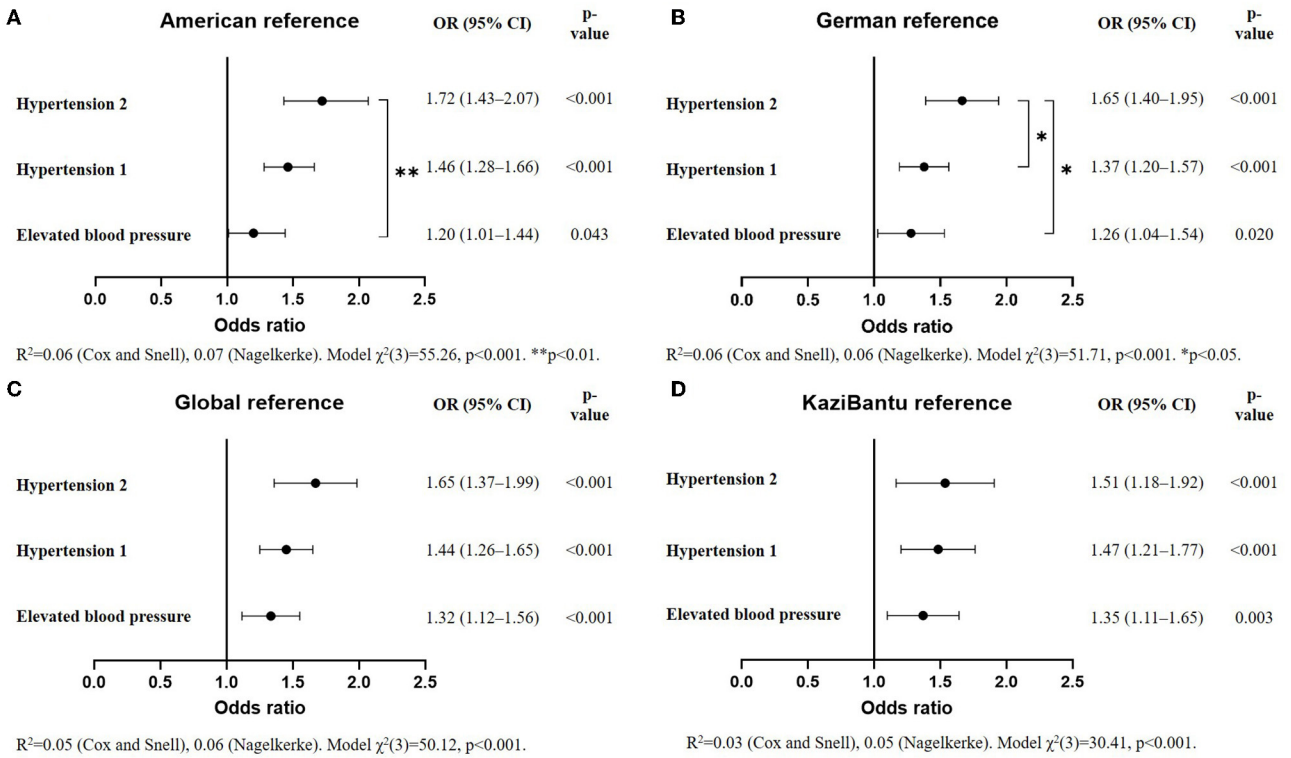

FIGURE 1 | Odds ratio (OR) of the classification of blood pressure (BP) as elevated, hypertension stage 1 or stage 2, relative to normotension, with increasing BMI-for-age Z-scores according to **(A)** American, **(B)** German, **(C)** global, and **(D)** the *KaziBantu* reference populations ($N = 897$).

used, to 28.8% based on international standards. Further analyzes show that the risk of being categorized as hypertensive with increasing levels of BAZ, a marker for adiposity, also varied among these standards, with the highest risk observed when international references were applied.

The first aim of the study was to establish and compare the prevalence of elevated BP and hypertension based on HIC standards, a pooled global reference, and pseudo-normative tables derived from the *KaziBantu* study population. We encountered a pronounced variability when different normative data were employed. International guidelines yielded the highest prevalence of hypertension in our study population at almost 30%. Although South Africa presents a higher hypertension prevalence than other sub-Saharan African countries, attributed partly to differences in countries' socioeconomic development (24), the estimates in the present study lie far above those reported by other authors. In fact, only one study has shown a higher combined hypertension prevalence of 32.6% (25). Interestingly, the authors used the German reference population from Neuhauser et al. (26). In contrast, when the *KaziBantu* pseudo-normative reference was used, hypertension prevalence was almost three times lower (11.4%) and thus, closer to the estimations found in the literature. However, they still remain higher than the 7.9% prevalence rates reported for Southern Africa (27) and the 8.1% for South Africa (8) in similar age groups. Nevertheless, it is noteworthy that a considerable heterogeneity exists within the South African literature, where pediatric hypertension ranges from 2.6 to 20.7% (28, 29).

This variability might be partly explained by methodological factors, such as the use of different instruments (electronic devices, sphygmomanometer, and finger-arterial pressure apparatus), or the number and occasions of BP readings (lowest of three readings, average of last two of three readings, average of three out of five measurements with the smallest variation). Arguably, we believe that this disparity is particularly governed by the use of different categorization standards and cut-offs. Many South African authors have based their estimations on outdated guidelines (29, 30), potentially leading to an underestimation of prevalence rates (31). Others have made use of the updated AAP 2017 guideline by applying simplified cut-offs. For example, Matjuda et al. considered exclusively percentiles disregarding whole values (in mm Hg) and age differences (<13 vs. >13 years) (10). In some studies, it is unclear whether researchers have developed pseudo-normative percentiles based on their own study population and subsequently classified them according to international standards (11, 32). Other studies do not describe the analysis altogether (33). Our results are in line with the disparities in hypertension estimates found in the literature and highlight an unstandardized use of methods and classification guidelines.

The discussion around the accuracy of hypertension estimates should however focus on their clinical significance, that is,

on establishing BP levels that relate to a real risk for early organ damage and CVD. Hence, other environmental and socioeconomic factors that influence BP should also be taken into account when applying standards that aim at stratifying risk across different contexts. Contrary to common belief, two recent meta-analyzes have shown that hypertension was more prevalent among LMICs than HICs (34, 35). The most affected are middle-transitioning economies like South Africa, which through unplanned and rapid urbanization are adopting westernized lifestyles, while communicable diseases continue to thrive (36). In fact, infections are a cause of undernutrition, anemia, and growth retardation, which, in turn, have been associated with hypertension (37). Similarly, lower socioeconomic status has been associated with higher prevalence of CVD risk factors (38) and hypertension (39). Kagura et al. corroborated these findings in adolescents from the township of Soweto in South Africa, showing a protective role for SBP with transition from low to high socioeconomic status (40). The previously exposed suggests that particular sociological, economic, and demographic characteristics account for the variability in the pattern of CVD risk factors and justify questioning the accuracy and significance of hypertension estimates, as well as their generalizability.

The second study aim was to evaluate whether the association of BMI with BP categorization differed between international references and pseudo-normative percentiles derived from the studied population, for the relation between obesity and elevated BP in African children has been extensively described in the literature (41–43). In the "Birth to Twenty" cohort from Soweto, adiposity in early life associated with the later development of elevated BP in black adolescents (44). Kruger et al. have reported a 60% increased risk of having hypertension per unit increase in BAZ in children from the Western Cape, South Africa (9). In our sample, American guidelines showed the highest increased risk for hypertension stage 2 at 72% compared to 51% with the *KaziBantu* pseudo-normative reference. In our view, the association of increasing BAZ levels with a higher risk for being ranked into upper BP categories obtained with the American guidelines speaks for a potentially better classification.

Furthermore, ∼50% of hypertension participants in the American and global references were hypertensive due to isolated systolic hypertension (ISH) compared to isolated diastolic and combined hypertension. This difference was not observed with the *KaziBantu* pseudo-normative reference. In the last years, SBP has gained relevance as a standalone risk factor for cardiovascular morbidity and mortality in adults (45). The primary prognostic significance of ISH has been observed in children too (46). Concluding, in our sample CVD risk understood as increased BMI-for-age levels and ISH was better predicted by the American and global guidelines.

Limitations

The results of the present study must be considered in light of the following limitations. First, international guidelines suggest that clinical hypertension needs to be confirmed as a high BP on three separate occasions since the prevalence of elevated BP tends to decrease over subsequent visits. In line with other epidemiological studies, we have measured BP on one visit and discarded the first reading to avoid an overestimation of results. Still, Kruger et al. stated that "by using three BP measurements during a single visit and averaging either all or the last two measurements, provides larger statistical variance and yields higher BP averages" (p. 8) (9).

Second, the study population has a specific profile of children living in low-income, urban areas of the Eastern Cape of South Africa, and is thus, not representative of the broad demographic spectrum characteristic of the population of South Africa. Furthermore, we had a relatively small population size, while simplified normative BP tables were calculated due to an unequal distribution of age. It is worth mentioning that while American and global guidelines both consist of a sample size of around 50,000 children, the relative small sample size of the *KaziBantu* study reference may have led to an underestimation of the hypertension prevalence and a weaker risk prediction potential.

Third, this study evaluated solely the association between BP and BMI to assess risk prediction of the standards, but did not collect data on other determinants of health that influence BP. Moreover, the design of the study does not allow to link BP levels to future adverse health events. Thus, it is not possible to draw definitive conclusions about suitability, or superiority, of any of the standards.

Our findings underscore the need for further research into the medical significance of current BP management guidelines in Southern Africa. Prospective longitudinal studies will be required to associate BP levels in childhood with the incidence of CVD and mortality later in life, and to establish clinically relevant cut-off values.

CONCLUSION

We found differences in hypertension prevalence depending on the normative BP tables applied to a population of 8- to 16-year-old children from disadvantaged communities in South Africa. Furthermore, we portray a marked underrepresentation of African children in international guidelines and a need for the standardization of BP data collection and analysis in this region. Hence, we advocate for the development of normative tables that are representative of the (South) African pediatric population (and other distinct populations currently not represented in panels informing international guidelines) and the definition of cutoffs that are based on clinical evidence to ensure accurate identification of hypertension both from the clinical and epidemiological perspective in marginalized populations. We conclude that until national or regional guidelines exist, large-enough international reference populations may be used in contexts different from the ones they were developed, albeit findings must be interpreted with caution.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Nelson Mandela University Ethics Committee (H18-HEA-HMS-001), Eastern Cape Department of Education, Eastern Cape Department of Health, Ethics Committee (EC_201804_00), and Northwest and Central Switzerland (R-2018-00047). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin, while oral assent was sought from children.

AUTHOR CONTRIBUTIONS

PA research idea, statistical analysis and interpretation of data, and draft preparation. JB and HS conceptualization and statistical analysis. IM, MG, and HS preparation of manuscript. LA, JD, DD, SG, NJ, IM, MN, and SN data collection and curation. All authors critical revision of the manuscript, provided approval for publication of the content, and agree to be accountable for the content of the work.

FUNDING

The work presented here was financially supported by the Novartis Foundation (Basel, Switzerland) and the Swiss National Science Foundation (Bern, Switzerland; grant no. 192651), and took place under the auspices of the UNESCO Chair on Physical Activity and Health in Educational Settings. The funders had no role in study design, data collection, data analysis or data interpretation, nor the decision to submit the manuscript for publication.

ACKNOWLEDGMENTS

The authors are grateful to the learners and parents/guardians for their participation in the study. We would especially like to thank Ms. Zaahira Ismail for her assistance with data collection and data management.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fped.2022.877431/full#supplementary-material

REFERENCES

1. World Health Organization. *Cardiovascular Diseases (Cvds).* (2021). Available online at: https://www.who.int/news-room/fact-sheets/detail/cardiovascular-diseases-(cvds) (accessed January 12, 2022).
2. Kruger R, Gafane-Matemane LF, Kagura J. Racial differences of early vascular aging in children and adolescents. *Pediatr Nephrol.* (2021) 36:1087–108. doi: 10.1007/s00467-020-04593-5
3. Climie RE, Park C, Avolio A, Mynard JP, Kruger R, Bruno RM. Vascular ageing in youth: a call to action. *Heart Lung Circ.* (2021) 30:1613–26. doi: 10.1016/j.hlc.2021.06.516
4. Nilsson PM, Lurbe E, Laurent S. The early life origins of vascular ageing and cardiovascular risk: the Eva syndrome. *J Hypertens.* (2008) 26:1049–57. doi: 10.1097/HJH.0b013e3282f82c3e
5. Kagura J, Ong KK, Adair LS, Pettifor JM, Norris SA. Paediatric hypertension in South Africa: an underestimated problem calling for action. *S Afr Med J.* (2018) 108:708–9. doi: 10.7196/SAMJ.2018.v108i9.13317
6. Song P, Zhang Y, Yu J, Zha M, Zhu Y, Rahimi K, et al. Global prevalence of hypertension in children: a systematic review and meta-analysis. *JAMA Pediatr.* (2019) 173:1154–63. doi: 10.1001/jamapediatrics.2019.3310
7. World Health Organization. *Obesity and Overweight.* (2021). Available online at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight (accessed January 14, 2022).
8. Noubiap JJ, Essouma M, Bigna JJ, Jingi AM, Aminde LN, Nansseu JR. Prevalence of elevated blood pressure in children and adolescents in Africa: a systematic review and meta-analysis. *Lancet Public Health.* (2017) 2:e375–86. doi: 10.1016/S2468-2667(17)30123-8
9. Kruger R, Kruger HS, Monyeki MA, Pienaar AE, Roux SB-L, Gafane-Matemane LF, et al. A demographic approach to assess elevated blood pressure and obesity in prepubescent children. *J Hypertens.* (2021) 39:2190–99. doi: 10.1097/HJH.0000000000002917
10. Matjuda EN, Engwa GA, Anye SNC, Nkeh-Chungag BN, Goswami N. Cardiovascular risk factors and their relationship with vascular dysfunction in south african children of African ancestry. *J Clin Med.* (2021) 10:354. doi: 10.3390/jcm10020354
11. Kagura J, Adair LS, Musa MG, Pettifor JM, Norris SA. Blood pressure tracking in urban black South African children: birth to twenty cohort. *BMC Pediatr.* (2015) 15:78. doi: 10.1186/s12887-015-0402-z
12. Shung-King M, Lake L, Sanders D, Hendricks M. Child and adolescent health – leave no one behind. *South Afr Child Gauge.* (2019) 264. Available online at: http://www.ci.uct.ac.za/cg-2019-child-and-adolescent-health
13. Expert Panel on Integrated Guidelines for Cardiovascular H, Risk Reduction in C, Adolescents, National Heart L, Blood I. Expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: summary report. *Pediatrics.* (2011) 128 (Suppl. 5):S213–56. doi: 10.1542/peds.2009-2107C
14. Lurbe E, Cifkova R, Cruickshank JK, Dillon MJ, Ferreira I, Invitti C, et al. Management of high blood pressure in children and adolescents: recommendations of the european society of hypertension. *J Hypertens.* (2009) 27:1719–42. doi: 10.1097/HJH.0b013e32832f4f6b
15. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. *Pediatrics.* (2017) 140:e20171904. doi: 10.1542/peds.2017-1904
16. Neuhauser H, Schienkiewitz A, Schaffrath AR, Dortschy R, Kurth B-M. *Referenzperzentile Für Anthropometrische Maßzahlen Und Blutdruck Aus Der Studie Zur Gesundheit Von Kindern Und Jugendlichen in Deutschalnd (Kiggs).* In: Bundes Gd, editor: Robert Koch-Institut. (2013). p. 101.
17. Xi B, Zong X, Kelishadi R, Hong YM, Khadilkar A, Steffen LM, et al. Establishing international blood pressure references among nonoverweight children and adolescents aged 6 to 17 years. *Circulation.* (2016) 133:398–408. doi: 10.1161/CIRCULATIONAHA.115.017936
18. Daniels SR. How to define hypertension in children and adolescents. *Circulation.* (2016) 133:350–1. doi: 10.1161/CIRCULATIONAHA.115.020531
19. Agirbasli M, Dilek HF, Tatlisu MA, Ankarali H. Reliability of normative tables in assessing elevated blood pressure in children. *J Hum Hypertens.* (2020) 34:241–7. doi: 10.1038/s41371-019-0290-z
20. Jobe M, Agbla SC, Prentice AM, Hennig BJ. High blood pressure and associated risk factors as indicator of preclinical hypertension in rural West Africa: a focus on children and adolescents in the Gambia. *Medicine.* (2017) 96:e6170. doi: 10.1097/MD.0000000000006170

21. Müller I, Smith D, Adams L, Aerts A, Damons BP, Degen J, et al. Effects of a school-based health intervention program in marginalized communities of port Elizabeth, South Africa (the Kazibantu Study): protocol for a randomized controlled trial. *JMIR Res Protoc.* (2019) 8:e14097. doi: 10.2196/14097
22. Rosner B. *Pediatric Blood Pressure.* (2021). Available online at: https://sites.google.com/a/channing.harvard.edu/bernardrosner/pediatric-blood-press (accessed June 25, 2021).
23. World Health Organization. *Growth Reference Data for 5-19 Years: Bmi-for-Age*. World Health Organization (2007). Available online at: https://www.who.int/growthref/who2007_bmi_for_age/en/ (accessed September 13, 2020).
24. Gomez-Olive FX, Ali SA, Made F, Kyobutungi C, Nonterah E, Micklesfield L, et al. Regional and sex differences in the prevalence and awareness of hypertension: an H3africa Awi-Gen study across 6 sites in sub-Saharan Africa. *Glob Heart.* (2017) 12:81–90. doi: 10.1016/j.gheart.2017.01.007
25. Gerber M, Müller I, Walter C, du Randt R, Adams L, Gall S, et al. Physical activity and dual disease burden among south african primary schoolchildren from disadvantaged neighbourhoods. *Prev Med.* (2018) 112:104–10. doi: 10.1016/j.ypmed.2018.04.001
26. Neuhauser HK, Thamm M, Ellert U, Hense HW, Rosario AS. Blood pressure percentiles by age and height from nonoverweight children and adolescents in Germany. *Pediatrics.* (2011) 127:e978–88. doi: 10.1542/peds.2010-1290
27. Crouch SH, Soepnel LM, Kolkenbeck-Ruh A, Maposa I, Naidoo S, Davies J, et al. Paediatric hypertension in africa: a systematic review and meta-analysis. *EClinicalMedicine.* (2022) 43:101229. doi: 10.1016/j.eclinm.2021.101229
28. Negash S, Agyemang C, Matsha TE, Peer N, Erasmus RT, Kengne AP. Differential prevalence and associations of overweight and obesity by gender and population group among school learners in South Africa: a cross-sectional study. *BMC Obes.* (2017) 4:29. doi: 10.1186/s40608-017-0165-1
29. Chungag A, Tata CM, Sewani-Rusike CR, Nel W, Nkeh-Chungag BN. Ellisras longitudinal study 2017: association of hypertension with increasing levels of adiposity in 10- to 14-year-old boys and girls in the Eastern Cape (Els 31). *Cardiovasc J Afr.* (2019) 30:258–61. doi: 10.5830/CVJA-2019-017
30. Gomwe H, Seekoe E, Lyoka P, Marange CS. The relationship between body composition and blood pressure among primary school children in Eastern Cape Province, South Africa. *Afr J Prim Health Care Fam Med.* (2019) 11:e1–6. doi: 10.4102/phcfm.v11i1.2000
31. Yang L, Kelishadi R, Hong YM, Khadilkar A, Nawarycz T, Krzywinska-Wiewiorowska M, et al. Impact of the 2017 American academy of pediatrics guideline on hypertension prevalence compared with the fourth report in an international cohort. *Hypertension.* (2019) 74:1343–8. doi: 10.1161/HYPERTENSIONAHA.119.13807
32. Nkeh-Chungag BN, Sekokotla AM, Sewani-Rusike C, Namugowa A, Iputo JE. Prevalence of hypertension and pre-hypertension in 13-17 year old adolescents living in Mthatha - South Africa: a cross-sectional study. *Cent Eur J Public Health.* (2015) 23:59–64. doi: 10.21101/cejph.a3922
33. Mokwatsi GG, Schutte AE, Kruger R. Ethnic differences regarding arterial stiffness of 6-8-year-old black and white boys. *J Hypertens.* (2017) 35:960–7. doi: 10.1097/HJH.0000000000001267
34. Mills KT, Bundy JD, Kelly TN, Reed JE, Kearney PM, Reynolds K, et al. Global disparities of hypertension prevalence and control: a systematic analysis of population-based studies from 90 countries. *Circulation.* (2016) 134:441–50. doi: 10.1161/CIRCULATIONAHA.115.018912
35. Zhou B, Perel P, Mensah GA, Ezzati M. Global epidemiology, health burden and effective interventions for elevated blood pressure and hypertension. *Nat Rev Cardiol.* (2021) 18:785–802. doi: 10.1038/s41569-021-00559-8
36. Mbogori T, Kimmel K, Zhang M, Kandiah J, Wang Y. Nutrition transition and double burden of malnutrition in Africa: a case study of four selected countries with different social economic development. *AIMS Public Health.* (2020) 7:425–39. doi: 10.3934/publichealth.2020035
37. Sawaya AL, Sesso R, Florêncio TMdMT, Fernandes MTB, Martins PA. Association between chronic undernutrition and hypertension. *Maternal Child Nutr.* (2005) 1:155–63. doi: 10.1111/j.1740-8709.2005.00033.x
38. Pisa PT, Behanan R, Vorster HH, Kruger A. Social drift of cardiovascular disease risk factors in Africans from the North West province of South Africa: the pure study. *Cardiovasc J Afr.* (2012) 23:371–8, e9–88. doi: 10.5830/CVJA-2012-018
39. Stringhini S, Forrester TE, Plange-Rhule J, Lambert EV, Viswanathan B, Riesen W, et al. The social patterning of risk factors for noncommunicable diseases in five countries: evidence from the modeling the epidemiologic transition study (Mets). *BMC Public Health.* (2016) 16:956. doi: 10.1186/s12889-016-3589-5
40. Kagura J, Adair LS, Pisa PT, Griffiths PL, Pettifor JM, Norris SA. Association of socioeconomic status change between infancy and adolescence, and blood pressure, in South African Young adults: birth to twenty cohort. *BMJ Open.* (2016) 6:e008805. doi: 10.1136/bmjopen-2015-008805
41. Kemp C. The prevalence of hypertension and the relationship with body composition in grade 1 learners in the North West Province of South Africa. *South Afr J Sports Med.* (2011) 23. doi: 10.17159/2078-516X/2011/v23i4a324
42. Chedjou-Nono E, Sap S, Choukem SP, Ngosso Tetanye I, Nebongo D, Koki Ndombo O. Cardiometabolic profile of obese children in a sub-saharan african setting: a cross-sectional study. *BMC Pediatr.* (2017) 17:129. doi: 10.1186/s12887-017-0880-2
43. Nyangasa MA, Buck C, Kelm S, Sheikh MA, Brackmann KL, Hebestreit A. Association between cardiometabolic risk factors and body mass index, waist circumferences and body fat in a Zanzibari cross-sectional study. *BMJ Open.* (2019) 9:e025397. doi: 10.1136/bmjopen-2018-025397
44. Munthali RJ, Kagura J, Lombard Z, Norris SA. Childhood adiposity trajectories are associated with late adolescent blood pressure: birth to twenty cohort. *BMC Public Health.* (2016) 16:665. doi: 10.1186/s12889-016-3337-x
45. Tin L, Beevers D, Lip G. Systolic vs diastolic blood pressure and the burden of hypertension. *J Hum Hypertens.* (2002) 16:147–50. doi: 10.1038/sj.jhh.1001373
46. Sorof JM. Prevalence and consequence of systolic hypertension in children. *Am J Hypertens.* (2002) 15:57S—60S. doi: 10.1016/S0895-7061(01)02303-2

Conflict of Interest: AA was employed by the company Novartis Foundation.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Chapter 4. Publication 2

Association of accelerometry-based and self-reported physical activity with cardiovascular risk in South African children

Patricia Arnaiz[1], Felix Guntlisbergen[1], Denis Infanger[1], Markus Gerber[1], Larissa Adams[2], Danielle Dolley[2], Nandi Joubert[1,3,4], Madeleine Nienaber[2], Siphesihle Nqweniso[2], Peter Steinmann[3,4], Rosa du Randt[2], Jürg Utzinger[3,4], Cheryl Walter[2], Uwe Pühse[1], Ivan Müller[1]

[1]Department of Sport, Exercise and Health, University of Basel, 4052 Basel, Switzerland.

[2]Department of Human Movement Science, Nelson Mandela University, 6031 Gqeberha*, South Africa.

[3]Swiss Tropical and Public Health Institute, 4002 Basel, Switzerland.

[4]University of Basel, 4001 Basel, Switzerland.

Published in:

South African Journal of Science. 2023; 119:15494.

The final publication is available at: https://doi.org/10.17159/sajs.2023/15494.

AUTHORS:
Patricia Arnaiz[1]
Felix Guntlisbergen[1]
Denis Infanger[1]
Markus Gerber[1]
Larissa Adams[2]
Danielle Dolley[2]
Nandi Joubert[1,3,4]
Madeleine Nienaber[2]
Siphesihle Nqweniso[2]
Rosa du Randt[2]
Peter Steinmann[3,4]
Jürg Utzinger[3,4]
Cheryl Walter[2]
Uwe Pühse[1]
Ivan Müller[1]

AFFILIATIONS:
[1]Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland
[2]Department of Human Movement Science, Nelson Mandela University, Gqeberha, South Africa
[3]Swiss Tropical and Public Health Institute, Allschwil, Switzerland
[4]University of Basel, Basel, Switzerland

CORRESPONDENCE TO:
Patricia Arnaiz

EMAIL:
patricia.arnaiz@unibas.ch

DATES:
Received: 24 Jan. 2023
Revised: 02 July 2023
Accepted: 03 July 2023
Published: 28 Sep. 2023

HOW TO CITE:
Arnaiz P, Guntlisbergen F, Infanger D, Gerber M, Adams L, Dolley D, et al. Association of accelerometry-based and self-reported physical activity with cardiovascular risk in South African children. S Afr J Sci. 2023;119(9/10), Art. #15494. https://doi.org/10.17159/sajs.2023/15494

ARTICLE INCLUDES:
☒ Peer review
☐ Supplementary material

DATA AVAILABILITY:
☒ Open data set
☐ All data included
☐ On request from author(s)
☐ Not available
☐ Not applicable

EDITOR:
Pascal Bessong

KEYWORDS:
physical activity, accelerometry, self-report, cardiovascular health, children, South Africa

FUNDING:
Novartis Foundation, Swiss National Science Foundation (grant no. 192651)

Association of accelerometry-based and self-reported physical activity with cardiovascular risk in South African children

The burden of non-communicable diseases is increasing, with risk factors emerging early in life. Physical activity reduces cardiovascular risk, but limited evidence exists for children from lower-income countries and mostly relies on self-reported methods that might be inaccurate and biased. We aimed to compare self-reported and accelerometer-measured physical activity in relation to cardiovascular risk markers in children from underserved communities in South Africa. We analysed cross-sectional data from 594 children aged 8 to 13. Physical activity was measured via accelerometry and the Physical Activity Questionnaire for Older Children (PAQ-C). Correlation analyses and linear regression models examined the relationship between accelerometer-measured and self-reported physical activity and their association with cardiovascular risk markers (body mass index, blood pressure, blood lipid profile and glycated haemoglobin). Results show a positive but weak correlation between PAQ-C scores and accelerometer-measured moderate-to-vigorous physical activity (MVPA). MVPA was inversely associated with body mass index, whilst sedentary behaviour correlated positively with lipid levels. PAQ-C scores were inversely associated with systolic blood pressure. The comparison of self-reported and accelerometer-measured physical activity in children from Gqeberha, South Africa, revealed inconsistencies in their correlation and association with cardiovascular risk markers. Accelerometry provided a more accurate cardiovascular risk estimation than PAQ-C, although associations were weak. Further, longitudinal studies should investigate the predictive power of both methodologies. These findings inform researchers and public health practitioners in the choice of method for physical activity appraisal beyond practical considerations, especially when combined with cardiovascular risk and in lower-income settings.

Significance:

We explore two widely used methods to assess physical activity levels in children. By comparing both methods, we expose inconsistencies in their correlation and association with cardiovascular risk markers. These data can guide researchers and public health practitioners in the use of one method beyond practical considerations. Whilst this work focuses on children from marginalised areas of South Africa, the issues explored are of relevance to other lower-income settings.

Introduction

Cardiovascular diseases (CVD) are the leading cause of death worldwide,[1] and their burden is increasing in low- and middle-income countries (LMICs).[2] Meanwhile, physical activity (PA) has substantial positive effects on CVD mortality. In fact, beneficial health outcomes begin with very modest amounts of moderate-to-vigorous physical activity (MVPA).[3] Although the positive effects of PA on cardiovascular health have already been observed in childhood, the relationship between PA and cardiovascular risk markers (CRMs) has predominantly been studied in adults.[4] Furthermore, most studies examining PA behaviour have originated from high-income countries (HICs).

Behaviours associated with PA are complex constructs that differ according to socioeconomic status, region and cultural context.[5] Yet, PA health benefits observed in HICs have been broadly extrapolated to LMICs due to the scarcity of evidence from these regions. An umbrella systematic review found that 3.1% of studies concerned with promoting PA in children and adolescents were from LMICs.[6] Of those, only one originated from Africa. This observation was corroborated by Guthold et al., who reported that sub-Saharan Africa had the least available data on PA amongst adolescents worldwide.[7] Moreover, estimates of PA levels in LMICs are heterogeneous, partly due to an unstandardised use of different measurement methods.

With current physical inactivity estimates arising from self-reported methods, a device-based PA data gap exists, especially in LMICs.[7] A systematic review of PA trends in sub-Saharan Africa found that 72.2% of studies relied on self-report methods to assess PA.[8] Self-reporting provides a convenient way to assess activity patterns across large populations in a short time.[9,10] However, self-reports are prone to inaccuracy and bias originating from recall errors, the social desirability effect and difficulties understanding the questions.[11] Wearable devices such as accelerometry are seen as a more accurate alternative,[12] as they can quantify energy expenditure and estimate the intensity, duration and frequency of PA.[13] Nevertheless, accelerometry technology is costly and time consuming, especially on a large scale, whilst it also involves a range of subjective decisions.[14] As a consequence, the lack of consensus on PA assessment instruments and data management limits the comparability of studies.

Multiple studies have exposed differences and paucity of agreement between self-report methods and device-based assessments. For example, the Scottish Health Survey 2003 found that more than 75% of children reported meeting the recommended 60 minutes of moderate-to-vigorous physical activity (MVPA) per day,[15] whilst other

studies from the United Kingdom using accelerometry reported a prevalence of less than 5%.[16-18] In South Africa, estimates for meeting PA recommendations range between 35.8%[8] and 77%[19] and vary both between and within instruments.[20-22] It is therefore not surprising that previous studies have shown a weak-to-moderate correlation between self-reported and device-based PA assessments.[13,23] Filling the PA data gap with more harmonised, device-based and larger sample studies is necessary to promote best PA practices in LMICs.[7]

Given the scarcity of data on PA behaviour from LMICs and the differences in the use and scope of self-report questionnaires versus accelerometry-based PA measurements, the aim of this study was twofold. First, we compared self-reported and accelerometer-measured PA amongst a large sample of school children from South Africa. Secondly, we examined their association with different CRMs. Based on the existing evidence, we hypothesised that self-reporting and accelerometry would vary in their PA estimates and association with CRMs.

Materials and methods

Study design and setting

This study was part of the KaziBantu project, a school-based intervention programme that attempts to promote sustainable lifestyle changes to achieve better health within disadvantaged communities in Gqeberha, South Africa. The *KaziBantu* programme was designed as a cluster-randomised controlled trial (RCT) and included eight schools that were randomly allocated to an intervention group (four schools) and a control group (four schools).[24] The study was structured such that after the completion of a baseline assessment in January 2019, children from the four intervention schools participated in the *KaziKidz* health promotion intervention for 32 weeks. The trial was registered at ISRCTN on 11 July 2018 under the registration number 18485542.

Participants

Data from 981 children were initially collected during a baseline assessment in early 2019. The children were aged between 8 and 16 years and were attending grades 4–6. Only children between the ages of 8 and 13 were retained in the final study sample, as there was only one child at age 14 and 16, respectively. After excluding children due to lack of consent or dropping out ($n = 14$), reporting an impairment during data collection ($n = 238$), not answering all questions from the PAQ-C ($n = 39$), having no or invalid ActiGraph measurements ($n = 75$), missing information on height and weight ($n = 27$), or being outside the age range ($n = 2$), the final study sample consisted of 586 children (301 boys and 285 girls). The minimal sample size was originally calculated for the cluster RCT, as described in the study protocol.[24] A posteriori power analysis conducted with G*Power 3.1 Software (Heinrich Heine Universität Düsseldorf, Germany) revealed that the sample of 586 participants was sufficiently powered to demonstrate a weak correlation ($r = 0.102$) between self-reported and accelerometry-based PA (assuming an alpha error of 0.05 and a power of 0.80).[25]

Data collection

Accelerometry-based assessment of physical activity

The ActiGraph accelerometry device (ActiGraph wGT3X-BT, Pensacola, Florida, USA) was used to measure PA. Participants were directed to wear the device for seven consecutive days around the hip. They were allowed to remove the ActiGraph for activities that involved water contact (e.g. swimming or showering). Accelerometers were set up at a sampling rate of 30 Hz and ran on the latest firmware version (version 1.9.2). Analysis was carried out with the ActiLife software (version 6.13.4), using data set up at epochs of 10 s.

To be eligible for the data evaluation, the ActiGraph had to be worn for at least four valid weekdays and at least one weekend day. A day was considered valid if the ActiGraph had been worn for at least eight hours during that day.[26] Sleep time was removed and during waking time, non-wear periods, defined and identified based on the Troiano 2007 algorithm, were excluded from the analysis. The different PA intensities were categorised according to the cut-off points from Evenson 2008 for children.[27]

Self-reported physical activity

A simplified version of the Physical Activity Questionnaire for Older Children (PAQ-C) was used to assess children's PA behaviour over the previous week.[28] Specifically, children ranked their personal PA level by answering questions 2–8, whereas question 10 inquired whether children were fit to perform PA. Later, a summary activity score between 1 and 5 (1 = lowest PA level, 5 = highest PA level) was calculated for questions 2–8. Children who reported sickness in question 10 or failed to answer one or more questions were excluded from the study sample ($n = 277$).

Blood pressure

Resting BP was measured after the children were directed to be seated for 5 min. BP was measured three times with a pause of 1 min between each measurement. A calibrated Omron digital blood pressure monitor (Omron M6 AC model; Hoofddorp, The Netherlands) was used by nurses or biokineticists for the measurements. Only the second and third measurements were used to calculate an average for systolic (SBP) and diastolic BP (DBP). Elevated blood pressure in children was defined as above 120/80 mmHg or the 90th percentile according to sex, age and height reference values.[29]

Blood lipid profiles and glycated haemoglobin

A point-of-care instrument (Alere Afinion AS 100 Analyzer, Abbott Technologies; Abbott Park, United States of America) was used to determine the blood lipid profiles (BLP) and glycated haemoglobin (HbA1c) concentrations. A healthcare worker first cleaned the fingertips with an alcohol swab and then pricked it with a safety lancet. Two drops of blood were carefully squeezed out of the finger, but only the second drop was collected for analysis. The device delivered the results within 8 min. All devices used were tested and calibrated before the procedure.[24]

The BLP included total cholesterol (TC), low-density lipoprotein (LDL), high-density lipoprotein (HDL), triglycerides (TG), non-high-density lipoprotein (non-HDL) and the ratio between TC and HDL (TC/HDL). Acceptable serum lipid and lipoprotein concentrations for children are <4.4 mmol/L for TC, <2.8 mmol/L for LDL, >1.2 mmol/L for HDL, <1 mmol/L for TG, <3.1 mmol/L for non-HDL and <3.7 for TC/HDL.[30] Levels of HbA1c revealed participants' average plasma glucose level over the past 8–12 weeks and were reported as a percentage of the total haemoglobin (%). Individuals with an HbA1c of 6.5% or higher are diagnosed with diabetes.[31]

Body mass index

The body height of the children was measured by a stadiometer with an accuracy of 0.1 cm. Participants were instructed to keep their backs erect, and their shoulders relaxed. The body weight was measured by standing on a digital weighing scale (Tanita MC-580; Tanita, Tokyo, Japan) with an accuracy of 0.1 kg. For each participant, the BMI was calculated by dividing body weight (kg) by the square of body height (m^2). Based on sex and age references specified by the World Health Organization (WHO), BMI for age was calculated and subsequently classified as "Thin" if it was below −2 standard deviation (SD), "Normal weight" if between −2 and 1 SD, "Overweight" if above 1 SD, or "Obese" if above 2 SD.[32]

Statistical analyses

Statistical analyses were conducted with the SPSS Statistics program (IBM SPSS Statistics for Mac, Version 27). Descriptive statistics were calculated as frequencies (%) for categorical variables and as medians (with interquartile range) for relatively symmetric, as well as skewed continuous variables. To identify differences between boys and girls, Mann–Whitney *U*-tests were conducted for continuous data, and Pearson's chi-squared tests were used for categorical data. Significance was set at $p \leq 0.05$ for all statistical analyses, and all tests were two-sided.

The relationship between PAQ-C scores and accelerometry-derived PA metrics was assessed using Spearman's rank correlation coefficients (ρ). Accelerometer wear time, age and sex were included as control variables. Cohen's correlation guidelines were used to evaluate the effect sizes as follows: $|\rho|$=0.1 small effect size, $|\rho|$=0.3 medium

effect size, $|\rho|=0.5$ large effect size.[33] Linear regression models were used to analyse the associations between PA and sedentary behaviour (SB) with CRMs. All models were adjusted for the influence of height, weight, sex, age and accelerometer wear time except BMI which was controlled only for sex, age and wear time. Unstandardised regression coefficients were used to assess effect size and discuss clinical relevance.

Ethics approval and consent to participate

The procedures of the *KaziBantu* study comply with the Declaration of Helsinki and have received ethical approval from the Nelson Mandela University Ethics Committee (reference #H18-HEA-HMS-001; dated 26 March 2018), Eastern Cape Department of Health (reference #EC_201804_007; dated 5 June 2018), and Eastern Cape Department of Education (dated 9 May 2018). The study was also cleared by the ethical review board of the Ethics Committee Northwest and Central Switzerland (reference #R-2018-00047; dated 1 March 2018). Each possible participant was informed about the study's objectives, procedures, risks and benefits. Participation in this study was voluntary and withdrawing was possible at any time with no further consequences. Oral approval (assent) had to be given by the participating children, whilst written informed consent was given by the corresponding parent or guardian.

Results

Descriptive characteristics

Characteristics of the study participants are presented in Table 1. With a median of 70.6 min of MVPA per day, 64.8% of the children achieved

Table 1: Descriptive characteristics of school-age children from Gqeberha, South Africa, in January 2019

Variable	All ($N = 586$)	Boys ($n = 301$)	Girls ($n = 285$)	p-value[a]	η^2 or Cramer's V[b]
Anthropometric					
Age	10.0 (10.0–11.0)	11.0 (10.0–11.0)	10.0 (9.0–11.0)	**0.002**	0.02
Height (cm)	139.5 (133.5–146.0)	138.6 (132.9–144.3)	140.8 (134.5–146.9)	**0.013**	0.01
Weight (kg)	33.3 (28.9–39.6)	32.1 (28.3–37.2)	35.4 (30.0–41.9)	**<0.001**	0.03
BMI[c] (kg/m^2)	17.1 (15.6–19.2)	16.7 (15.4–18.2)	17.8 (15.8–20.3)	**<0.001**	0.03
Blood pressure					
SBP[d] (mmHg)	107.8 (99.0–116.3)	106.5 (98.0–115.5)	109.0 (99.5–117.0)	**0.032**	0.01
DBP[e] (mmHg)	65.5 (60.5–71.5)	64.5 (59.5–69.8)	66.5 (61.5–72.5)	**0.019**	0.01
Blood lipid profile					
TG[f] (mmol/L)	0.8 (0.6–1.0)	0.7 (0.6–0.9)	0.9 (0.7–1.2)	**<0.001**	0.07
TC[g] (mmol/L)	3.7 (3.3–4.2)	3.6 (3.2–4.1)	3.8 (3.4–4.3)	**0.010**	0.01
LDL[h] (mmol/L)	2.0 (1.7–2.4)	1.9 (1.6–2.4)	2.0 (1.7–2.4)	0.063	0.01
HDL[i] (mmol/L)	1.3 (1.1–1.5)	1.3 (1.1–1.5)	1.3 (1.1–1.5)	0.168	<0.01
Non-HDL[j] (mmol/L)	2.4 (2.0–2.8)	2.3 (2.0–2.8)	2.5 (2.1–2.9)	**<0.001**	0.03
TC/HDL[k] (ratio)	2.9 (2.5–3.3)	2.8 (2.4–3.2)	3.0 (2.7–3.5)	**<0.001**	0.03
Blood sugar					
HbA1c[l] (%)	5.4 (5.3–5.6)	5.4 (5.3–5.6)	5.4 (5.3–5.6)	0.383	<0.01
PAQ-C[m]					
Median score (1–5)	2.9 (2.4–3.4)	3.0 (2.4–3.6)	2.7 (2.3–3.2)	**<0.001**	0.02
ActiGraph					
Sedentary time (%)	64.2 (60.3–67.9)	62.4 (58.7–66.5)	65.6 (61.9–69.0)	**<0.001**	0.06
Light activity time (%)	28.9 (26.0–31.6)	29.2 (26.0–31.8)	28.6 (26.0–31.1)	0.154	<0.01
Moderate activity time (%)	4.8 (3.8–6.1)	5.5 (4.4–6.7)	4.1 (3.3–5.1)	**<0.001**	0.16
Vigorous activity time (%)	2.0 (1.3–2.9)	2.5 (1.8–3.6)	1.6 (1.1–2.1)	**<0.001**	0.18
MVPA[n] (min/day)	70.6 (52.6–89.4)	83.8 (64.4–104.1)	57.7 (45.5–75.2)	**<0.001**	0.21
Wear time (min/day)	1034.0 (1002.1–1053.4)	1040.6 (1008.7–1059.6)	1028.5 (997.2–1049.3)	**<0.001**	0.03
Meets physical activity guidelines[o] (Yes/No; %)	64.8/35.2	81.7/18.3	47.0/53.0	**<0.001**	0.37

Note: Values in bold indicate statistically significant results. Data are median (IQR) or percentage.

[a]Between-sex differences assessed by Mann-Whitney-U-Test or Pearson's chi-square test. [b]Effect size indicated by η^2 for continuous data and Cramer's V for categorical data. [c]Body mass index; [d]Systolic blood pressure, [e]Diastolic blood pressure, [f]Triglycerides, [g]Total cholesterol, [h]Low-density lipoprotein, [i]High-density lipoprotein, [j]Difference between TC and HDL, [k]Ratio between TC and HDL, [l]Glycated haemoglobin, [m]Physical Activity Questionnaire for Older Children, [n]Moderate- to vigorous-intensity physical activity, [o]More than or equal to (Yes), or less than (No) 60 minutes of MVPA per day.

the recommended minimum of 60 min of MVPA per day. Overall, study participants spent 64.2% of their daily time in SB, 28.9% in light PA, 4.8% in moderate PA, and 2.0% in vigorous PA. The median wear time of the ActiGraph accelerometer was 17.2 h per day. The median PAQ-C score was 2.9, which lies slightly above half the possible value between 1 (lowest) and 5 (highest).

Significant differences were found between girls and boys. BMI, SBP, DBP, TG, TC, non-HDL, and TC/HDL were higher in girls than in boys (BMI: 17.8 vs. 16.7, $p < 0.001$; SBP: 109.0 mmHg vs. 106.5 mmHg, $p = 0.032$; DBP: 66.5 mmHg vs. 64.5 mmHg, $p = 0.019$; TG: 0.9 mmol/L vs. 0.7 mmol/L, $p < 0.001$; TC: 3.8 mmol/L vs. 3.6 mmol/L, $p = 0.010$; non-HDL: 2.5 mmol/L vs. 2.3 mmol/L, $p < 0.001$; TC/HDL: 3.0 vs. 2.8, $p < 0.001$). Boys were significantly more active than girls, as indicated by both the questionnaire (3.0 vs. 2.7, $p < 0.001$) and accelerometry (MVPA min/day 83.8 vs. 57.7, $p < 0.001$), and spent less time engaging in SB than girls (62.4% vs. 65.6%, $p < 0.001$, respectively). The WHO recommendations for PA were achieved by 81.7% of boys compared with only 47.0% of girls.

Correlation analysis between PAQ-C and wGT3X-BT ActiGraphy

We found significant but weak associations between PAQ-C scores and PA metrics measured by the ActiGraph accelerometry (Table 2). The PAQ-C scores were positively associated with average MVPA minutes per day (ρ=0.10, $p = 0.015$). The PAQ-C scores also correlated with the percentage of time spent engaging in moderate- or vigorous-intensity activities (ρ=0.09, $p = 0.035$; ρ=0.10, $p = 0.013$, respectively). However, we found little evidence for an association between PAQ-C scores and the time spent in SB ($p = 0.72$) or light PA ($p = 0.31$). Association patterns are depicted in Figure 1.

Associations between physical activity and sedentary behaviour with cardiovascular risk markers

Significant associations were observed between selected CRMs and PA metrics measured by PAQ-C and ActiGraph (Table 3). The ActiGraph MVPA was significantly and inversely associated with BMI (MVPA: beta=−0.031; CI = −0.043, −0.020; $p < 0.001$). The PAQ-C scores were inversely associated with SBP (beta=−1.563; CI = −2.926, −0.200; $p = 0.025$). Time spent in SB was positively associated with TC, LDL and non-HDL (TC: beta=0.001, CI = 0.000, 0.002, $p = 0.018$; LDL: beta=0.001, CI = 0.001, 0.002, $p = 0.002$; non-HDL: beta=0.001, CI = 0.000, 0.002, $p = 0.008$). Figure 2 provides a graphical representation of significant association patterns. We found little evidence for an association of DBP, HDL, TG, TC/HDL and HbA1c with self-reported PA levels or with accelerometer-measured MVPA and SB.

Discussion

This study compared self-reported (PAQ-C) and accelerometry-based (ActiGraphy) PA and their association with selected CRMs in a population of school-aged children from underserved communities in South Africa. It was found that PAQ-C scores were weakly associated with ActiGraph-measured MVPA and that the two PA assessment methods were inconsistent in detecting relationships with CRMs.

PAQ-C scores correlated positively with ActiGraph-measured MVPA levels. Thus, children who rated themselves as being more physically active according to their PAQ-C scores achieved higher levels of MVPA as measured via accelerometry. However, the strength of the relationship between the two methods was weak. These findings agree with the results from other studies questioning the convergent validity of the PAQ-C.[34-36] A recent meta-analysis by Marasso and colleagues identified a moderate pooled correlation coefficient between the PAQ-C

Table 2: Spearman rank correlations between PAQ-C scores and ActiGraph measurements of physical activity ($N = 586$)

Self-reported physical activity	Accelerometer-measured physical activity				
	Average MVPA[a] (min/day)	***Sedentary time (%)***	***Light activity time (%)***	***Moderate activity time (%)***	***Vigorous activity time (%)***
PAQ-C[b] score (1–5)	**0.101 ($p = 0.015$)**	−0.015 ($p = 0.719$)	−0.042 ($p = 0.309$)	**0.087 ($p = 0.035$)**	**0.103 ($p = 0.013$)**

Note: Values in bold indicate statistically significant results; models are adjusted for sex, age and accelerometer wear time.

[a]Moderate- to vigorous-intensity physical activity, [b]Physical Activity Questionnaire for Older Children

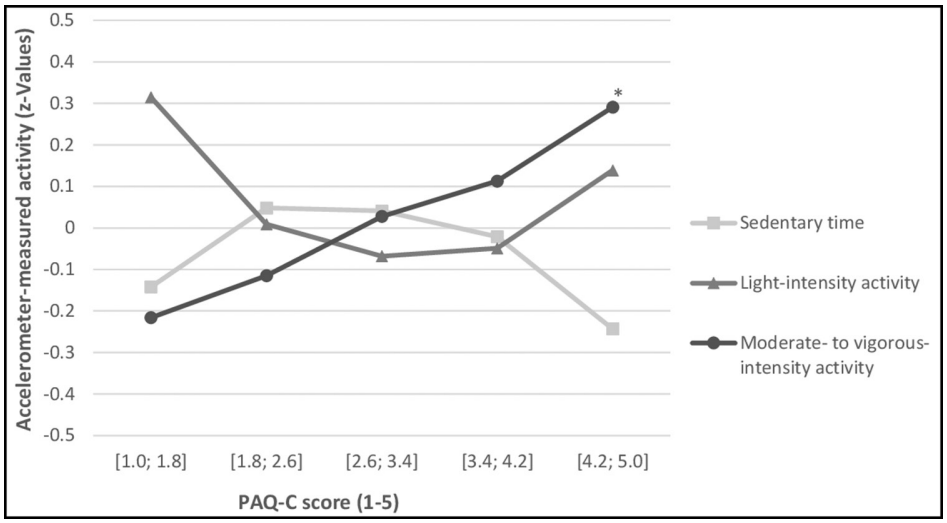

Figure 1: Correlation between accelerometry-based and self-reported physical activity. Moderate-to-vigorous physical activity showed a significant positive correlation with Physical Activity Questionnaire for Older Children (PAQ-C) scores (*$p = 0.015$) in school-aged children from Gqeberha, South Africa.

Table 3: Associations between cardiovascular risk markers with physical activity and sedentary behaviour

Dependent variable		PAQ-C[a] score (1–5)			ActiGraph MVPA[b] (min/day)			Sedentary time (min/day)		
	N	*beta*	95% CI	*p*-value	*beta*	95% CI	*p*-value	*beta*	95% CI	*p*-value
BMI[c,d] (kg/m²)	586	–0.383	–0.773, 0.006	0.054	**–0.031**	**–0.043, –0.020**	**<0.001**	<0.001	–0.005, 0.005	0.989
SBP[e] (mmHg)	577	**–1.563**	**–2.926, –0.200**	**0.025**	0.012	–0.031, 0.055	0.584	–0.002	–0.021, 0.017	0.814
DBP[f] (mmHg)	577	–0.911	–2.077, 0.255	0.125	0.006	–0.030, 0.043	0.729	–0.002	–0.018, 0.015	0.852
TC[g] (mmol/L)	492	0.068	–0.008, 0.143	0.079	<0.001	–0.002, 0.003	0.834	**0.001**	**0.000, 0.002**	**0.018**
LDL[h] (mmol/L)	486	0.033	–0.029, 0.095	0.294	<0.001	–0.002, 0.002	0.894	**0.001**	**0.001, 0.002**	**0.002**
HDL[i] (mmol/L)	492	0.020	–0.015, 0.054	0.260	<0.001	–0.001, 0.001	0.627	<0.001	0.000, 0.001	0.817
TG[j] (mmol/L)	492	0.062	–0.004, 0.129	0.067	<0.001	–0.002, 0.002	0.912	–0.001	–0.001, 0.000	0.254
Non-HDL[k] (mmol/L)	492	0.048	–0.017, 0.112	0.146	<0.001	–0.002, 0.002	0.988	**0.001**	**0.000, 0.002**	**0.008**
TC/HDL[l] (ratio)	492	0.015	–0.057, 0.087	0.685	<0.001	–0.002, 0.002	0.937	0.001	0.000, 0.002	0.155
HbA1c[m] (%)	500	0.008	–0.019, 0.035	0.548	<0.001	–0.001, 0.001	0.569	<0.001	0.000, 0.000	0.629

Note: Values in bold indicate statistically significant results. Unstandardised coefficients (beta) from linear regression models were adjusted for sex, age, height, weight and accelerometer wear time. The number of children included in models (N) varies due to missing data for some cardiovascular risk markers.

[a]Physical Activity Questionnaire for Older Children; [b]Moderate-to-vigorous physical activity; [c]Body mass index; [d]Model adjusted only for sex, age and wear time; [e]Systolic blood pressure, [f]Diastolic blood pressure, [g]Total cholesterol, [h]Low-density lipoprotein, [i]High-density lipoprotein, [j]Triglycerides, [k]Difference between TC and HDL, [l]Ratio between TC and HDL, [m]Glycated haemoglobin

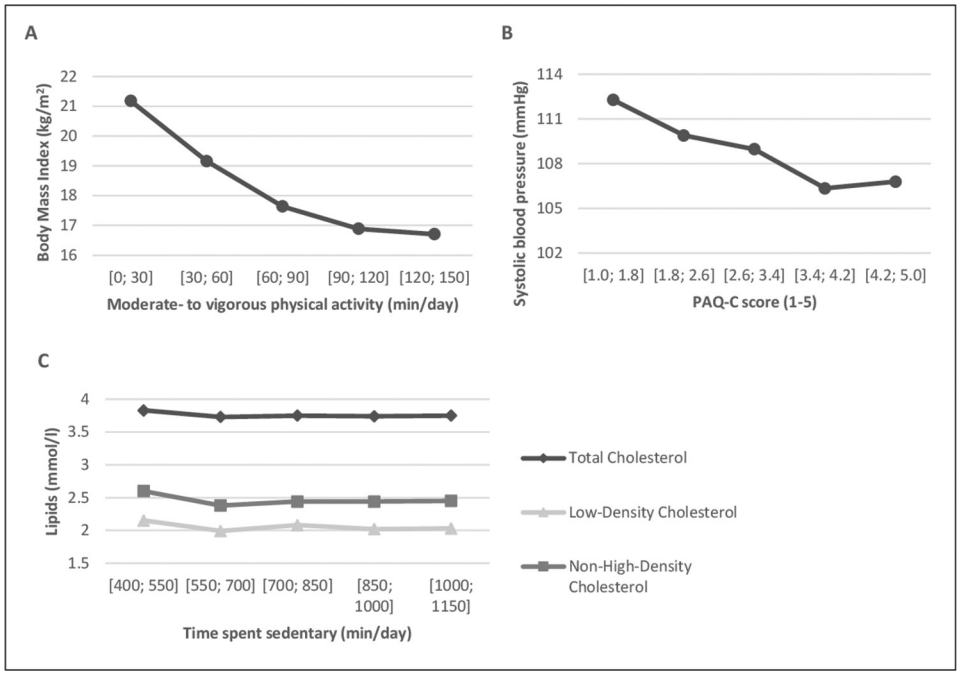

Figure 2: Significant associations between physical activity and cardiovascular risk markers. A significant inverse association between (A) accelerometer-measured MVPA and BMI and (B) PAQ-C scores and SBP. (C) A positive association between SB and lipids can be observed for school-aged children from Gqeberha, South Africa.

and accelerometry measurements, whilst also reporting wide correlation variability in the studies included. The low correlation coefficient and the weak explanatory power observed in this study contribute to the notion that PAQ-C and accelerometry have an inconsistent agreement for measuring MVPA. Furthermore, the PAQ-C would not fulfil the standards of a PA questionnaire proposed by Terwee et al., whereby correlation coefficients with accelerometer-measured MVPA must be at least moderate.[37] Because we only included valid accelerometry data in our analyses to ensure a representative mean wear time (17.23 out of a maximum of 18 h), we deem the presented accelerometry-based assessments as accurate. Therefore, we argue that attempting to derive children's objective MVPA levels from their PAQ-C scores, and vice versa, is linked to a high level of uncertainty.

Differences between self-reported and accelerometer-measured PA can be interpreted as children's difficulties in assessing their own PA habits. It has been observed that memory errors play an important role, particularly when dealing with children.[38] Another factor potentially contributing to discrepancies is the social desirability bias, where study participants report higher PA levels to be viewed favourably by others. Moreover, differences might stem from the ActiGraph not being able to accurately measure activities with little upper body movement such as cycling. During cycling, the upper body is not accelerated in any direction as happens when, for example playing soccer, a popular activity amongst children in South Africa.[39] Previous studies have also pointed out that the PAQ-C and accelerometry do not actually measure the same construct.[40] Accelerometry measures the exact duration, frequency and intensity of body movement, whilst the PAQ-C provides information about self-reported PA behaviour, activity types and settings in which PA is performed. Hence, the simultaneous use of PAQ-C and accelerometry could allow for a more comprehensive study of the relationship between self-perceived and actual PA and customised PA recommendations.

Regarding cardiometabolic risk, ActiGraph-measured MVPA was inversely related to BMI. Increasing MVPA by 15 min per day was associated with a BMI reduction of approximately −0.47 points. The significant association between accelerometer-measured MVPA and BMI demonstrates that PA, particularly MVPA, can be a crucial contributor to weight control at a young age.[41] Especially girls should be encouraged to increase their time spent in MVPA, as they spent substantially less time in MVPA and showed higher BMI values compared to boys (57.7 vs. 83.8 min/day and 17.8 vs. 16.7 kg/m^2, respectively). In contrast, children's self-reported PA levels were not significantly associated with BMI. Thus, children who considered themselves as more physically active did not exhibit lower BMI values. More consistent associations with BMI for device-based PA than for self-reported PA have previously been reported and were attributed to self-report bias.[42]

Diverging results were also obtained for the association between PA and SBP. In this study, SBP was weakly and inversely associated with self-reported PA but not with ActiGraph MVPA levels. Research has not shown that self-reported PA estimates are more likely to identify a significant association with BP compared with device-based PA measurements. In contrast, some studies have observed a significant inverse association between PA and BP using device-based methods,[43-45] although this relationship has not always been established.[46-48] The inconsistency of findings on the relationship between PA and BP amongst children and adolescents may be explained by varying durations of PA measurement, a lack of consistency in methodology, the influence of childhood adiposity, and wide ranges of age groups included in the studies.[49]

The activity assessment by accelerometry also provides estimates of the time children spend in SB, which allowed for the analysis of the association between CRMs and physical inactivity. Higher levels of SB were related to small increases in TC, LDL and non-HDL concentrations, whilst neither self-reported nor accelerometer-measured PA was associated with any BLP parameter. Increasing daily SB by 15 min was associated with a predicted increase of +0.015 mmol/L in TC, LDL and non-HDL. Because girls showed higher levels of SB compared to boys (65.6 vs. 62.4% per day, respectively) and higher concentrations in TC (3.8 vs. 3.6 mmol/L, respectively) and non-HDL (2.5 vs. 2.3 mmol/L, respectively), they should particularly be encouraged to reduce time spent in SB. It has been hypothesised that PA and SB have independent effects on lipoprotein metabolism, with PA more strongly affecting HDL and TG, and SB being rather related to the 'bad' cholesterol (LDL and non-HDL).[50] Consistent with the findings of this study, it has been claimed that PA does not lower LDL and TC.[51] However, the significant effect of MVPA on HDL and TG that has been previously observed was not found in this study.[52] Our results conform to those of the European Youth Heart Study that revealed non-significant relationships between MVPA and BLP.[53]

The results of this work must be interpreted considering the following limitations. First, this study has a cross-sectional design, which means that causality cannot be inferred because temporality is not known. Second, 8.0% of children with ActiGraph data were excluded from the analyses due to not meeting our wear time requirements. Third, PA was assessed over the period of 1 week, but since PA is highly variable in children, the measure comprised 1 week may not fully reflect children's true PA levels. Fourth, the limitations of the assessment methods must be considered. PAQ-C is prone to recall errors, social desirability effect and difficulties understanding the questions. Also, more than 25% of study participants reported that an impairment had prevented them from engaging in their usual PA and were therefore not included in the analysis. Limitations of the ActiGraph accelerometry include its inability to accurately measure activities with little upper body movement such as cycling or weight training when worn around the hip. Lastly, the impact of children's dietary habits was not accounted for in the associations between PA and SB with CRMs.

Conclusion

We found a weak relationship between self-reported (PAQ-C) and accelerometer-measured (ActiGraph) MVPA levels in a paediatric population from low-income areas in South Africa. Thus, we advise caution when comparing studies that are based on diverse methodologies for assessing PA. As PA measured via accelerometry and SB showed stronger associations with CRMs, the wearable device ActiGraph allowed for a more accurate CVD risk estimation compared to the PAQ-C questionnaire. However, our results point towards a weak association between PA and CRMs. Therefore, it is of interest to further investigate the association between different PA measurement methods in longitudinal studies, especially under researched paediatric populations from LMICs.

Acknowledgements

We thank all members of the *KaziBantu* team who contributed to the realisation of the project and who were involved in data collection in Gqeberha, South Africa. We also appreciate all learners of the *KaziBantu* schools in Gqeberha for their participation in the project and the teachers and principals for ensuring smooth collaboration. We thank the reviewers for their inputs and acknowledge the Novartis Foundation (Basel, Switzerland) and the Swiss National Science Foundation (Bern, Switzerland) for funding the research.

Competing interests

We have no competing interest to declare.

Authors' contributions

P.A.: Conceptualisation, writing – the initial draft, data compilation, data curation, interpretation of results, student supervision. F.G.: Conceptualisation, writing – the initial draft, data compilation, statistical analyses, interpretation of results. D.I.: Statistical input, writing – revisions. M.G.: Writing – revisions. L.A.: Data collection, writing – revisions. D.D.: Data collection, writing – revisions. N.J.: Data collection, writing – revisions. M.N.: Data collection, writing – revisions. S.N.: Data collection, writing – revisions. R.d.R.: Writing – revisions. P.S.: Writing – revisions. J.U.: Writing – revisions. C.W.: Writing – revisions. U.P.: Writing – revisions. I.M.: Conceptualisation, data collection, writing – revisions.

References

1. WHO. The top 10 causes of death [webpage on the Internet]. c2020 [cited 2021 Jul 05]. Available from: https://www.who.int/news-room/fact-sheets/detail/the-top-10-causes-of-death
2. Roth GA, Abate D, Abate KH, Abay SM, Abbafati C, Abbasi N, et al. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: A systematic analysis for the Global Burden of Disease Study 2017. The Lancet. 2018;392(10159):1736–1788.
3. Kraus WE, Powell KE, Haskell WL, Janz KF, Campbell WW, Jakicic JM, et al. Physical activity, all-cause and cardiovascular mortality, and cardiovascular disease. Med Sci Sports Exerc. 2019;51(6):1270–1281. https://doi.org/10.1249/MSS.0000000000001939
4. Ruiz JR, Ortega FB. Physical activity and cardiovascular disease risk factors in children and adolescents. Curr Cardiovasc Risk Rep. 2009;3(4):281–287. https://doi.org/10.1007/s12170-009-0043-6
5. Siefken K, Varela AR, Waqanivalu T, Schulenkorf N. Physical activity in low- and middle-income countries. 1st ed. London: Routledge; 2022. Available from: https://www.taylorfrancis.com/books/9780429344732
6. Barbosa Filho VC, Minatto G, Mota J, Silva KS, de Campos W, Lopes A da S. Promoting physical activity for children and adolescents in low- and middle-income countries: An umbrella systematic review. Prev Med. 2016;88:115–126. https://doi.org/10.1016/j.ypmed.2016.03.025
7. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1·6 million participants. Lancet Child Adolesc Health. 2020;4(1):23–35. https://doi.org/10.1016/S2352-4642(19)30323-2
8. Muthuri SK, Onywera VO, Tremblay MS, Broyles ST, Chaput JP, Fogelholm M, et al. Relationships between parental education and overweight with childhood overweight and physical activity in 9–11 year old children: Results from a 12-country study. PLoS ONE. 2016;11(8), e0147746. https://doi.org/10.1371/journal.pone.0147746
9. Nigg CR, Fuchs R, Gerber M, Jekauc D, Koch T, Krell-Roesch J, et al. Assessing physical activity through questionnaires – A consensus of best practices and future directions. Psychol Sport Exerc. 2020;50:101715. https://doi.org/10.1016/j.psychsport.2020.101715
10. Benítez-Porres J. Cut-off values for classifying active children and adolescentes using the Physical Activity Questionnaire: PAQ-C and PAQ-A. Nutr Hosp. 2016;33(5). Available from: http://revista.nutricionhospitalaria.net/index.php/nh/article/view/564
11. Sallis JF. Self-report measures of children's physical activity. J Sch Health. 1991;61(5):215–219. https://doi.org/10.1111/j.1746-1561.1991.tb06017.x
12. Burchartz A, Anedda B, Auerswald T, Giurgiu M, Hill H, Ketelhut S, et al. Assessing physical behavior through accelerometry – State of the science, best practices and future directions. Psychol Sport Exerc. 2020;49:101703. https://doi.org/10.1016/j.psychsport.2020.101703
13. Marasso D, Lupo C, Collura S, Rainoldi A, Brustio PR. Subjective versus objective measure of physical activity: A systematic review and meta-analysis of the convergent validity of the physical activity questionnaire for children (PAQ-C). Int J Environ Res Public Health. 2021;18(7):3413. https://doi.org/10.3390/ijerph18073413
14. Prince SA, Adamo KB, Hamel M, Hardt J, Connor Gorber S, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: A systematic review. Int J Behav Nutr Phys Act. 2008;5(1):56. https://doi.org/10.1186/1479-5868-5-56
15. Scottish Executive. Scottish health survey 2003: Summary of key findings. Edinburgh: Scottish Executive The Stationery Office; 2005.
16. Ness AR, Leary SD, Mattocks C, Blair SN, Reilly JJ, Wells J, et al. Objectively measured physical activity and fat mass in a large cohort of children. PLoS Med. 2007 March 20;4(3), e97. https://doi.org/10.1371/journal.pmed.0040097
17. Reilly J, Jackson D, Montgomery C, Kelly L, Slater C, Grant S, et al. Total energy expenditure and physical activity in young Scottish children: Mixed longitudinal study. The Lancet. 2004;363(9404):211–212. https://doi.org/10.1016/S0140-6736(03)15331-7
18. Riddoch CJ, Mattocks C, Deere K, Saunders J, Kirkby J, Tilling K, et al. Objective measurement of levels and patterns of physical activity. Arch Dis Child. 2007;92(11):963–969. https://doi.org/10.1136/adc.2006.112136
19. Sedumedi CM, Janssen X, Reilly JJ, Kruger HS, Monyeki MA. Association between objectively determined physical activity levels and body composition in 6–8-year-old children from a black South African population: BC–IT study. Int J Environ Res Public Health. 2021;18(12):6453. https://doi.org/10.3390/ijerph18126453
20. Nqweniso S, Walter C, du Randt R, Aerts A, Adams L, Degen J, et al. Prevention of overweight and hypertension through cardiorespiratory fitness and extracurricular sport participation among South African schoolchildren. Sustainability. 2020;12(16):6581. https://doi.org/10.3390/su12166581
21. Salvini M, Gall S, Müller I, Walter C, du Randt R, Steinmann P, et al. Physical activity and health-related quality of life among schoolchildren from disadvantaged neighbourhoods in Port Elizabeth, South Africa. Qual Life Res. 2018;27(1):205–216. https://doi.org/10.1007/s11136-017-1707-1
22. Van Biljon A, McKune AJ, DuBose KD, Kolanisi U, Semple SJ. Physical activity levels in urban-based South African learners: A cross-sectional study of 7 348 participants. S Afr Med J. 2018;108(2):126. https://doi.org/10.7196/SAMJ.2017.v108i2.12766
23. Koolhaas C, Van Rooij F, Cepeda M, Tiemeier H, Franco O, Schoufour J. Physical activity derived from questionnaires and wrist-worn accelerometers: Comparability and the role of demographic, lifestyle, and health factors among a population-based sample of older adults. Clin Epidemiol. 2017;10:1–16. https://doi.org/10.2147/CLEPS147613
24. Müller I, Smith D, Adams L, Aerts A, Damons BP, Degen J, et al. Effects of a school-based health intervention program in marginalized communities of Port Elizabeth, South Africa (the Kazibantu study): Protocol for a randomized controlled trial. JMIR Res Protoc. 2019;8(7), e14097. https://doi.org/10.2196/14097
25. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. Behav Res Methods. 2009;41(4):1149–1160. https://doi.org/10.3758/BRM.41.4.1149
26. Janz KF, Medema-Johnson HC, Letuchy EM, Burns TL, Gilmore JME, Torner JC, et al. Subjective and objective measures of physical activity in relationship to bone mineral content during late childhood: The Iowa Bone Development Study. Br J Sports Med. 2008;42(8):658–663. https://doi.org/10.1136/bjsm.2008.047779
27. Evenson KR, Catellier DJ, Gill K, Ondrak KS, McMurray RG. Calibration of two objective measures of physical activity for children. J Sports Sci. 2008;26(14):1557–1565. https://doi.org/10.1080/02640410802334196
28. Kowalski KC, Crocker PRE, Donen RM. The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual. Saskatoon: University of Saskatchewan; 2004. Available from: https://www.prismsports.org/UserFiles/file/PAQ_manual_ScoringandPDF.pdf
29. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. Pediatrics. 2017;140(3), e20171904. https://doi.org/10.1542/peds.2017-3035
30. Orimadegun BE. Dyslipidaemia in African children and adolescents. In: Management of Dyslipidemia [Internet]. IntechOpen; 2021 [cited 2022 Jan 16]. Available from: https://doi.org/10.5772/intechopen.96804
31. The International Expert Committee. International expert committee report on the role of the A1C assay in the diagnosis of diabetes. Diabetes Care. 2009;32(7):1327–1334. https://doi.org/10.2337/dc09-9033
32. WHO. BMI-for-age (5-19 years) [webpage on the Internet]. c2007 [cited 2021 Nov 9]. Available from: https://www.who.int/tools/growth-reference-data-for-5to19-years/indicators/bmi-for-age
33. Cohen J. Statistical power analysis for the Behavioral Sciences. 2nd ed. New York: Routledge; 1988.
34. Benítez-Porres J, López-Fernández I, Raya JF, Álvarez Carnero S, Alvero-Cruz JR, Álvarez Carnero E. Reliability and validity of the PAQ-C questionnaire to assess physical activity in children. J Sch Health. 2016;86(9):677–685. https://doi.org/10.1111/josh.12418
35. Ben Jemaa H, Mankaï A, Mahjoub F, Kortobi B, Khlifi S, Draoui J, et al. Physical activity level assessed by accelerometer and PAQ-C in Tunisian children. Ann Nutr Metab. 2018;73(3):234–240. https://doi.org/10.1159/000492673
36. Chan CHS, Ha ASC, Ng JYY, Lubans DR. Associations between fundamental movement skill competence, physical activity and psycho-social determinants in Hong Kong Chinese children. J Sports Sci. 2019;37(2):229–236. https://doi.org/10.1080/02640414.2018.1490055

37. Terwee CB, Mokkink LB, Van Poppel MNM, Chinapaw MJM, Van Mechelen W, De Vet HCW. Qualitative attributes and measurement properties of physical activity questionnaires: A checklist. Sports Med. 2010;40(7):525–537. https://doi.org/10.2165/11531370-000000000-00000

38. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. Sports Med. 2001;31(6):439–454. https://doi.org/10.2165/00007256-200131060-00004

39. Alegi P, Bolsmann C. South Africa and the global game: Football, apartheid and beyond. London: Routledge; 2010.

40. Ham SA, Reis JP, Strath SJ, Dubose KD, Ainsworth BE. Discrepancies between methods of identifying objectively determined physical activity. Med Sci Sports Exerc. 2007;39(1):52–58. https://doi.org/10.1249/01.mss.0000235886.17229.42

41. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act. 2010;7(40):16. https://doi.org/10.1186/1479-5868-7-40

42. Wanner M, Richard A, Martin B, Faeh D, Rohrmann S. Associations between self-reported and objectively measured physical activity, sedentary behavior and overweight/obesity in NHANES 2003–2006. Int J Obes. 2017;41(1):186–193. https://doi.org/10.1038/ijo.2016.168

43. Owen CG, Nightingale CM, Rudnicka AR, Sattar N, Cook DG, Ekelund U, et al. Physical activity, obesity and cardiometabolic risk factors in 9- to 10-year-old UK children of white European, South Asian and black African-Caribbean origin: The Child Heart And health Study in England (CHASE). Diabetologia. 2010;53(8):1620–1630. https://doi.org/10.1007/s00125-010-1781-1

44. Leary SD, Ness AR, Smith GD, Mattocks C, Deere K, Blair SN, et al. Physical activity and blood pressure in childhood: Findings from a population-based study. Hypertension. 2008;51(1):92–98. https://doi.org/10.1161/HYPERTENSIONAHA.107.099051

45. Andersen LB, Riddoch C, Kriemler S, Hills A. Physical activity and cardiovascular risk factors in children. Br J Sports Med. 2011;45(11):871–876. https://doi.org/10.1136/bjsports-2011-090333

46. Brage S, Wedderkopp N, Ekelund U, Franks PW, Wareham NJ, Andersen LB, et al. Features of the metabolic syndrome are associated with objectively measured physical activity and fitness in Danish children. Diabetes Care. 2004;27(9):2141–2148. https://doi.org/10.2337/diacare.27.9.2141

47. Craig SB, Bandini LG, Lichtenstein AH, Schaefer EJ, Dietz WH. The impact of physical activity on lipids, lipoproteins, and blood pressure in preadolescent girls. Pediatrics. 1996;98(3):389–395. https://doi.org/10.1542/peds.98.3.389

48. Klesges RC, Keith Haddock C, Eck LH. A multimethod approach to the measurement of childhood physical activity and its relationship to blood pressure and body weight. J Pediatr. 1990;116(6):888–893. https://doi.org/10.1016/S0022-3476(05)80645-6

49. Knowles G, Pallan M, Thomas GN, Ekelund U, Cheng KK, Barrett T, et al. Physical activity and blood pressure in primary school children: A longitudinal study. Hypertension. 2013;61(1):70–75. https://doi.org/10.1161/HYPERTENSIONAHA.112.201277

50. Celis-Morales CA, Perez-Bravo F, Ibañez L, Salas C, Bailey MES, Gill JMR. Objective vs. self-reported physical activity and sedentary time: effects of measurement method on relationships with risk biomarkers. PLoS ONE. 2012;7(5), e36345. https://doi.org/10.1371/journal.pone.0036345

51. Ahmed HM, Blaha MJ, Nasir K, Rivera JJ, Blumenthal RS. Effects of physical activity on cardiovascular disease. Am J Cardiol. 2012;109(2):288–295. https://doi.org/10.1016/j.amjcard.2011.08.042

52. Carroll S, Dudfield M. What is the relationship between exercise and metabolic abnormalities?: A review of the metabolic syndrome. Sports Med. 2004;34(6):371–418. https://doi.org/10.2165/00007256-200434060-00004

53. Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S, et al. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: The European youth heart study. Diabetologia. 2007;50(9):1832–1840. https://doi.org/10.1007/s00125-007-0762-5

Chapter 5. Publication 3

Sustainability of a school-based health intervention for prevention of non-communicable diseases in marginalized communities: protocol for a mixed-methods cohort study

Patricia Arnaiz[1], Larissa Adams[2], Ivan Müller[1], Markus Gerber[1], Cheryl Walter[2], Rosa du Randt[2], Peter Steinmann[3,4], Manfred Max Bergman[5], Harald Seelig[1], Darelle van Greunen[6], Jürg Utzinger[3,4], Uwe Pühse[1]

[1]Department of Sport, Exercise and Health, University of Basel, 4052 Basel, Switzerland.

[2]Department of Human Movement Science, Nelson Mandela University, 6031 Gqeberha, South Africa.

[3]Swiss Tropical and Public Health Institute, 4002 Basel, Switzerland.

[4]University of Basel, 4001 Basel, Switzerland.

[5]Department of Social Sciences, University of Basel, 4051 Basel, Switzerland.

[6]Centre for Community Technologies, Nelson Mandela University, 6031 Gqeberha, South Africa.

Published in:

BMJ Open. 2021; 11:e047296.

The final publication is available at: https://doi.org/10.1136/bmjopen-2020-047296.

BMJ Open

Sustainability of a school-based health intervention for prevention of non-communicable diseases in marginalised communities: protocol for a mixed-methods cohort study

Patricia Arnaiz ,[1] Larissa Adams,[2] Ivan Müller,[1] Markus Gerber ,[1] Cheryl Walter,[2] Rosa du Randt,[2] Peter Steinmann ,[3,4] Manfred Max Bergman,[5] Harald Seelig,[1] Darelle van Greunen,[6] Jürg Utzinger,[3,4] Uwe Pühse[1]

To cite: Arnaiz P, Adams L, Müller I, *et al*. Sustainability of a school-based health intervention for prevention of non-communicable diseases in marginalised communities: protocol for a mixed-methods cohort study. *BMJ Open* 2021;**11**:e047296. doi:10.1136/bmjopen-2020-047296

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2020-047296).

Received 24 November 2020
Accepted 18 September 2021

For numbered affiliations see end of article.

Correspondence to
Dr Patricia Arnaiz;
patricia.arnaiz@unibas.ch

ABSTRACT

Introduction The prevalence of chronic, lifestyle-related diseases is increasing among adults and children from low-income and middle-income countries. Despite the effectiveness of community-based interventions to address this situation, the benefits thereof may disappear in the long term, due to a lack of maintenance, especially among disadvantaged and high-risk populations. The *KaziBantu* randomised controlled trial conducted in 2019 consisted of two school-based health interventions, *KaziKidz* and *KaziHealth*. This study will evaluate the long-term effectiveness and sustainability of these interventions in promoting positive lifestyle changes among children and educators in disadvantaged schools in Nelson Mandela Bay, South Africa, in the context of the COVID-19 pandemic.

Methods and analysis This study has an observational, longitudinal, mixed-methods design. It will follow up educators and children from the *KaziBantu* study. All 160 educators enrolled in *KaziHealth* will be invited to participate, while the study will focus on 361 *KaziKidz* children (aged 10–16 years) identified as having an increased risk for non-communicable diseases. Data collection will take place 1.5 and 2 years postintervention and includes quantitative and qualitative methods, such as anthropometric measurements, clinical assessments, questionnaires, interviews and focus group discussions. Analyses will encompass: prevalence of health parameters; descriptive frequencies of self-reported health behaviours and quality of life; the longitudinal association of these; extent of implementation; personal experiences with the programmes and an impact analysis based on the Reach, Efficacy, Adoption, Implementation, Maintenance framework.

Discussion In settings where resources are scarce, sustainable and effective prevention programmes are needed. The purpose of this protocol is to outline the design of a study to evaluate *KaziKidz* and *KaziHealth* under real-world conditions in terms of effectiveness, being long-lasting and becoming institutionalised. We hypothesise that a mixed-methods approach will increase understanding of the interventions' capacity to lead to sustainable favourable health outcomes amid challenging environments, thereby generating evidence for policy.

Trial registration number ISRCTN15648510

Strengths and limitations of this study

- The cohort of children was purposely and objectively identified based on their high-risk profile; the follow-up of personal health outcomes is of additional value.
- The mixed-methods approach, strengthened by the involvement of the community and key stakeholders, will enable a comprehensive evaluation of the programmes.
- Internationally recognised measurement methods for quantitative, as well as qualitative, were selected and adapted to the study setting.
- The COVID-19 pandemic might influence schools' decision to discontinue or adapt the post-*KaziBantu* intervention and the research team will assess, but not influence, its implementation.
- The study will yield context-specific results that will be closely linked to COVID-19 measures and practices adopted by the schools.

INTRODUCTION

Socioeconomic, environmental and cultural factors exert a significant influence on children's health and well-being.[1] In impoverished communities in low-income and middle-income countries (LMICs), children are especially vulnerable to illness and lags in age-appropriate development, negatively affecting their life prospects.[2–4] This precarious situation has been aggravated by the COVID-19 pandemic, which has compromised millions of South African children's education, mental health and nutrition.[5] Furthermore, the disease profile of urban

populations from LMICs is approaching that of high-income countries, as the proportion of deaths attributable to chronic, lifestyle-related diseases increases.[6–8] Of particular concerns are changing dietary habits and sedentary lifestyle patterns,[9 10] both known to lead to metabolic and physiological changes, such as obesity and hypertension, also in young children.[11 12] Children presenting with cardiometabolic risk factors are at particularly high risk because of their predisposition to developing non-communicable diseases (NCDs) later in life.[13 14] Thus, a reduction of undesired behaviours could potentially prevent the majority of chronic diseases, indicating a great need for prevention programmes and awareness campaigns.[15 16]

Global recommendations for physical activity (PA) stipulate a daily minimum of 60 min of moderate-to-vigorous PA for children between 5 and 17 years old. Walter showed that the levels of in-school PA among children from marginalised communities in South Africa do not meet the minimal requirements,[17] which was later confirmed by 'The Healthy Active Kids South Africa Report Card' (2018).[18] Therefore, there is an urgent need to promote PA among at-risk communities in South Africa. Several school-based lifestyle interventions have proved effective in increasing levels of PA and reducing obesity in children from different contexts.[19–21] However, very few school-based and large-scale PA intervention studies have been conducted in South Africa. The first study, *HealthKick*, was set in disadvantaged low-income communities in Cape Town and aimed at promoting healthy eating habits and regular participation in PA in children to reduce the risk of chronic diseases.[22] Study results were not completely satisfactory and highlighted that educators play a key role in implementing lifestyle interventions in schools.[23 24] Some studies have reported beneficial effects of integrated community-based interventions involving the participation of educators and children.[25–27]

'Disease, Activity and Schoolchildren's Health' study documented the poor health status and double burden from communicable and NCDs of children in disadvantaged communities in Gqeberha, formerly known as Port Elizabeth, South Africa.[28] It also revealed the potential for improvement through PA and health literacy interventions, following the principles that PA is key for the promotion of health and well-being among school children, and that learning this at a young age will have long-lasting effects throughout life. Moreover, it emphasised the role of educators as influential and willing advocates.[29] Building on these results and experience, *KaziBantu*, a comprehensive school-based lifestyle intervention programme aiming at promoting health literacy in both children and educators of primary schools from disadvantaged communities in Nelson Mandela Bay (NMB) was developed.[30] *KaziBantu*, which is a composite Swahili and isiXhosa phrase meaning «Active People», was designed as a dual approach consisting of two school-based health promotion interventions, *KaziKidz* for children and *KaziHealth* for educators, and was implemented as a cluster randomised controlled trial (RCT) between January and October 2019. Preliminary results show that more than half of the assessed children (544/975) presented at least one risk factor for NCDs. Educators responded positively to the intervention as they felt the programme was also focused on their health and well-being (individualised results were communicated to the study participants) and took cognizance of the difficult work environment they faced daily.

Furthermore, evidence suggests that general and work-related stress increases the risk of mental ill health (burnout, anxiety, impaired quality of sleep), as well as physical disease (coronary heart disease and musculoskeletal disease). These factors seem to contribute to an increased risk of premature death.[31] This risk was confirmed in a large representative sample of South African educators (N=21 307) working in public schools. High stress levels, lack of job satisfaction and different stress-related physical illnesses (hypertension, heart disease, stomach ulcers, mental distress, tobacco and alcohol misuse) were reported.[32]

Although evidence exists on the effectiveness of community-based lifestyle interventions in LMICs,[33] studies have also shown that positive effects tend to disappear in the long term,[34] sometimes because programmes fail to be maintained.[35 36] In addition, there is still a scarcity of evidence regarding the feasibility of educational programmes in at-risk populations in disadvantaged school settings. We hypothesise that a comprehensive approach focusing specifically on high-risk children and their educators might increase implementation feasibility and ultimately lead to sustainable favourable health outcomes in both groups.

Objectives

The goal of this follow-up study is to determine the long-term post-RCT effectiveness, adoption and continuity of both *KaziKidz* and *KaziHealth* school-based health interventions in disadvantaged primary schools in NMB, South Africa, under real-world conditions and amid the COVID-19 pandemic. To achieve this goal, the following objectives are set:

1. To assess the effectiveness of the interventions in promoting long-lasting, positive lifestyle changes among children and educators, thereby reducing risk factors for NCDs;
2. To evaluate the postintervention sustainability concerning the continuation of the programme implementation in the schools as well as the institutionalisation within the Eastern Cape Department of Education (ECDoE) in South Africa.
3. To provide recommendations towards guidelines for a health promotion framework, as well as its adaption to new contexts that may be translated into policy and practice.

METHODS

Research setting

This study is conducted in the eight schools originally selected for the *KaziBantu* RCT.[30] These are quintile

three primary schools in the townships and Northern areas of NMB, in the Eastern Cape province of South Africa. The quintiles of South African schools are determined through the national poverty table and are ranged on a scale from 1 (poorest) to 5 (least poor). Quintile three schools represent no-fee paying schools and their communities are adversely affected by poverty and high unemployment rates.

Study population

Originally, in the *KaziBantu* project, both *KaziKidz* and *KaziHealth* interventions were conducted in four schools, whereas the other four participating schools were used as controls.[30] In total, 975 children from fourth to sixth grade (aged 8–16 years) were enrolled in the study; 482 children were allocated to the intervention and 493 to the control arm. At the same time, 160 educators were enrolled among all participating schools; of those, 85 took part in *KaziHealth,* whereas 75 served as waiting-list controls.

This study will follow up children and educators from the *KaziBantu* trial. While all educators who took part in *KaziHealth* have been invited to participate in this follow-up phase, a cohort of children from the *KaziKidz* intervention, who have been identified as having an increased risk for NCDs, have been included in this study. We have defined increased risk as a child presenting at least one of the following cardiometabolic risk factors: (1) overweight or obesity, (2) elevated blood pressure or hypertension, (3) pre-diabetes or diabetes, (4) borderline or dyslipidaemia; according to age appropriate, standard classifications (table 1) and based on *KaziBantu* baseline data from July 2019. Of the 975 children who participated in *KaziKidz*, 544 were classified as «high risk» according to the above-mentioned definition. Since then, 183 children have graduated from primary school resulting in 361 eligible learners. Of those, 240 have consented to participate and have been enrolled in this follow-up study at the time this protocol was published. Of the 160 educators enrolled in the *KaziHealth* program in 2019, 105 have consented to participate and have been enrolled in this study so far.

Table 1 Classification criteria for cardiometabolic risk in children

Risk factor	Indicators and cut-off points
Adiposity[59 60]	BMI-for-age (SD)
Overweight	>+1 and ≤+2
Obesity	>+2
Blood pressure[61 62]	SBP and/or DBP (percentiles and mm Hg)
Elevated blood pressure	≥90th and <95th or <90th but ≥120/80
Hypertension stage 1	≥95th and ≤99th or ≥130/80
Hypertension stage 2	>99th or ≥140/90
Glycaemia[63]	HbA1c (mmol/mol)
Pre-diabetes	>39 and <48
Diabetes	≥48
Dyslipidaemia[64 65]	TC (mmol/l)
Borderline	≥4.40 and 5.15
Dyslipidaemia	≥5.15

BMI, body mass index; DBP, diastolic blood pressure; HbA1c, glycated haemoglobin; SBP, systolic blood pressure; TC, total cholesterol.

Intervention

The *KaziKidz* intervention consists of a tailored, ready-made teaching material toolkit for grades 1–7 and addresses children's risk factors for NCDs, health behaviours and psychosocial health. On the other hand, *KaziHealth* is designed as a workplace intervention targeting educators' health and well-being through health risk assessments and personalised lifestyle coaching. The interventions have been described in detail elsewhere[30] and all teaching materials and other project resources are freely available online.[37]

After conclusion of the *KaziBantu* RCT in 2019, all eight schools were given the freedom to conduct *KaziKidz* and *KaziHealth*. Thus, all children from grades 1–7 may have participated in *KaziKidz*, regardless of health condition. However, the implementation of *KaziKidz* and *KaziHealth* has proceeded independently and without support from the project team in all schools, under so-called «real-world» conditions. Therefore, the delivery of the programmes might have been only partially implemented. For instance, some schools might have needed to adapt *KaziKidz* to comply with COVID-19-related requirements, while other schools might have not been able to, or decided not to, continue with the intervention at all.

Study design

This study represents an observational follow-up of the *KaziBantu* RCT and has been designed as a longitudinal study to investigate the long-term effects of both lifestyle interventions, *KaziKidz* and *KaziHealth*, on health parameters and behaviours of a cohort of high-risk children, as well as all educators originally included in the RCT. The overall effectiveness and sustainability of the programmes will be assessed using a mixed-methods approach, including quantitative and qualitative data collection methods and analyses (figure 1). Recruitment has started in March 2021. Assessments of health outcomes will be performed both for children and educators at two time points: April 2021 and September 2021, that is, 1.5 and 2 years post-RCT, to evaluate the maintenance of healthy, active lifestyles and its effect on an individual level. As part of the postintervention evaluation, the extent of *KaziKidz*'s implementation in the schools will be obtained from school representatives at both time points to be able to correlate the observed outcomes with

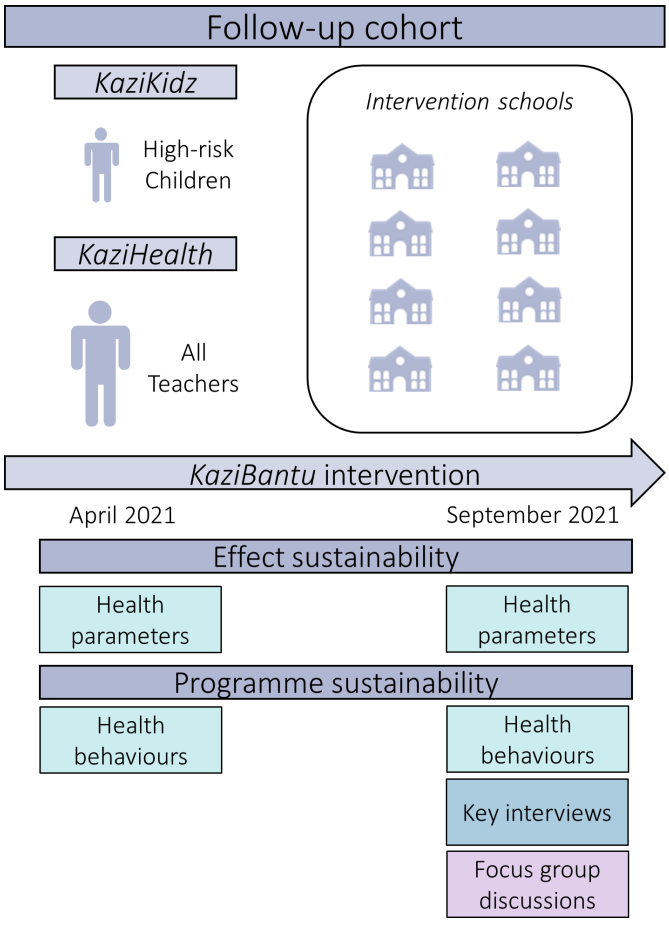

Figure 1 Overview of the follow-up study design to assess the sustainability and effectiveness of *KaziKidz* and *KaziHealth*.

continued participation in the original intervention. A qualitative analysis of the school headmasters' experiences with *KaziKidz,* as well as of its incorporation into the schools' curriculum with officials from the ECDoE, will take place 2 years post-RCT, in October 2021. Additionally, qualitative analyses will also be conducted with school educators on their experiences with, and incorporation of, *KaziHealth* into their lifestyles 2 years post-RCT, in October 2021. Further information on the adoption and acceptance of *KaziKidz* by educators and parents, and of *KaziHealth* by school headmasters' and ECDoE officials will be obtained during October 2021.

This postintervention sustainability assessment does not involve the evaluation of programme delivery adequacy. Similarly, the research team will not influence the effect that «real-world» conditions might have on whether, or how, the interventions are delivered in the schools. Since the studied cohort does not involve the follow-up of a control group, participants from schools refusing the implementation would serve as comparison groups for potential health and behavioural effects.

Data collection

Primary outcomes include anthropometric and clinical examinations, self-reported and objectively measured PA, self-reported diet and self-reported psychosocial health, while secondary outcomes include age, sex, socioeconomic status (SES)and school. Standard procedures to assess the interventions' health effects on markers for NCD risk factors will be conducted by well-trained professional staff (eg, biokineticists), who will adhere to standardised, quality-controlled protocols established during previous work of the research group in the area.

Anthropometric measurements: Body weight will be measured on a digital weighing scale and body height against a stadiometer with back erect and shoulders relaxed. Body mass index (BMI) will be calculated as weight (kg)/height (m),^{2} and additionally, BMI-for-age stratified by sex will be determined for children according to WHO growth charts. Waist circumference will be measured with a steel tape between the rib cage and the iliac crest and hip circumference at the maximal circumference of the buttocks; waist-to-hip ratio will be calculated as waist circumference/hip circumference. Body fat percentage will be assessed via bioelectrical impedance analysis (BIA) with a wireless body composition monitor (Tanita MC-580; Tanita, Tokyo, Japan) in participants at least 3 hours after food consumption.

Clinical examinations: Blood pressure will be measured three times after the participant has been seating for 5 min. The Omron digital blood pressure monitor and appropriate cuffs sized 17–22 cm for children and 22–32 or 32–42 cm for adults will be used for this purpose and will be wrapped around the left arm with the bottom of the cuff placed about 4 cm above the elbow and the palm facing up. The blood pressure will be estimated as the average value of the second and third measurement. A full blood lipid profile will assess total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol (HDL-C), triglycerides, non-HDL cholesterol and cholesterol to HDL ratio with the Alere Afinion AS 100 Analyzer point-of-care testing instrument. Glycated haemoglobin (HbA1c) will be measured from the second of two blood drops extracted from the fingertip previously cleaned with alcohol and pricked with a safety lancet, using the Alere Afinion AS 100 Analyzer. Haemoglobin concentration will be assessed for educators with the HemoCue Hb 301 system.

Objective measurement of physical behaviours: PA will be measured for each participant using an accelerometer (ActiGraph wGT3X-BT, Pensacola, Florida, USA) which will be worn around the hip, at all times, for 7 days (five weekdays and two weekend days), except for activities involving water contact.

Questionnaires: Information on PA during school hours and in their free time will be self-reported by children using adjusted questions from the PA Questionnaire for Children.[38] Dietary behaviours and nutrition will be self-reported by children through a tailored, validated food frequency questionnaire[39 40] and by educators via a 24-hour dietary recall questionnaire.[41] The validated KIDSCREEN-10 questionnaire, European generic health-related quality-of-life questionnaire (10-domain version),

will be implemented to determine children's physical and psychological well-being.[42 43] Where necessary, questionnaires will be translated into the home language of the children, isiXhosa or Afrikaans, and additionally explained orally by students of the Nelson Mandela University. Self-reported psychosocial health in educators will be assessed through general perceived stress (four-item Perceived Stress Scale),[44] work-related stress (Effort-Reward Imbalance),[45] work and family conflict (Work and Family Conflict Scale),[46] and burn-out symptoms (Shirom-Melamed Burnout Measure[47]) questionnaires. Information about educators' work attendance will be obtained from the schools' attendance registers. A self-developed questionnaire will be used to assess the continuity and extent of *KaziKidz*'s implementation in the schools and will be answered by the school representative.

The support for, and integration into the school curriculum of, *KaziKidz* and *KaziHealth* sustainability will be studied by qualitative research, employing credibility, transferability, dependability, confirmability and authenticity as quality criteria when employing qualitative methods .[48]

Interviews: Information on the strengths, challenges and prospects of the *KaziKidz* toolkit implementation in the schools and the Eastern Cape school curricula will be collected via semistructured interviews. Interviewees will include principals from all participating schools (n=8), as well as representatives from the ECDoE (n=1), Provincial Teacher Development Institute (n=1) and the Nelson Mandela University (n=1). The interview schedule pertains to the perceived strengths, weaknesses, acceptance and degree of integration of the intervention programme into the school curriculum.

Focus groups: Information on community feasibility and community acceptance of *KaziKidz* and *KaziHealth* will be gathered during 16 focus group discussion (FGD) sessions of eight participants each. For *KaziKidz*, six focus groups will be organised and will include 24 parents and 24 educators from previous intervention and control schools. The sessions will last approximately 60 min. Parents and educators will be part of different groups to focus on the feasibility and acceptance of the programme at home and in schools, respectively. For *KaziHealth*, eight focus groups will include educators from all schools, whereas two other sessions will be organised with all eight schools' principals, on the one hand, and officials from the ECDoE, on the other.

Data management

Throughout the study, personal data will be anonymised. All data will be saved on SWITCHdrive, a Swiss non-commercial cloud data storage service for institutions of higher education. Stored data will be backed up weekly and the principal investigator will supervise the content to ensure data quality. Data collected will be accessible only to authorised personnel (investigators and ethics committee members) and exclusively used for scientific research. Quantitative data will be double-entered and validated in EpiData V.3.1 and once cleaned, transferred to STATA V.15.1 for statistical analysis. Interviews and FGDs will be audiorecorded, transcribed and coded. At the end of the study, data will be anonymised and shared using the publicly accessible data repository, Zenodo.

Data analysis

Anthropometric, clinical indicators and objectively measured PA will be characterised by means and SD, if they are close to the normal distribution, and otherwise by medians and IQRs. Data on self-reported health status, PA and dietary patterns collected in questionnaires will be treated as categorical data and described by their frequency distributions. The interview and FGD data will be analysed using qualitative content analysis,[49] and each interview and focus group transcript will be cross-coded to locations and thematic fit. To improve intercoder reliability, two independent coders will be employed. The results of the qualitative analyses will include a taxonomy of the perceived strengths, challenges and implementation of the intervention programme.

Cross-sectional analysis

Mixed linear models: Associations of continuous health and PA outcomes with personal characteristics (eg, sex, SES) will be assessed postintervention, that is, from data collected after the conclusion of the trial. It will be adjusted for the type of school (ie, intervention vs control) and potential clustering within schools and classes, respective random intercepts will be used.

Mixed logistic regression: For categorical outcome measures, after suitable dichotomisation of polytomous outcomes, associations with the same predictor variables as for the mixed linear models will be analysed postintervention using the same random intercepts.

Longitudinal analysis

Mixed linear regression: Associations between longitudinal changes in continuous variables (eg, BMI) and individual characteristics, like sex and SES, will be assessed with random intercepts for schools and classes. Longitudinal changes in these outcomes will also be compared between the previous intervention and control schools after adjustment for personal characteristics. Moreover, changes in health parameters will be regressed against changes in PA and nutritional parameters. All analyses will be conducted, with and without adjustment, for the postintervention values of the respective outcomes. Also, potential associations between adjusted school-specific means of longitudinal changes in health parameters and the retrospectively assessed degrees of implementation of intervention measures in the respective schools will be assessed.

Mixed logistic regression: Longitudinal changes in categorical outcomes will be analysed by dichotomising polytomous outcomes. Analyses will be stratified according to the postintervention value of the dichotomised outcome, using mixed logistic regression models of the follow-up

Table 2 Impact analysis evaluation based on the RE-AIM framework

Dimensions	Social level	Evaluation criteria
Reach Proportion of the target population that has participated in the intervention	Individual: Children Educators	Number and characteristics of children who: ► Have received at least half the planned lessons, as reported by the educators. Number and characteristics of educators who: ► Have received the health risk assessment. ► Have attended at least one face-to-face coaching session.
Efficacy Success rate of the intervention in reducing risk factors	Individual: Children Educators	Changes in: ► Anthropometric measurements. ► Clinical parameters. ► Quality of life.
Adoption Proportion of settings that has incorporated the intervention	Organisational: School educators School principals	Number and characteristics of: ► Schools that implemented the intervention. ► Health-promoting activities per school.
	Community: School educators Parents	Number and characteristics of: ► Educators who have adopted *KaziHealth* recommendations. ► Parents aware of and supporting *KaziKidz* activities.
Implementation Extent to which the intervention has been embedded in the schools under naturalistic conditions	Organisational: School principals	Number of: ► Grades and classes participating in the intervention. ► Terms per school year in which the intervention is being taught. ► Staff involved in delivering the intervention.
Maintenance Adherence to and dissemination of the intervention	Individual: Children Educators	Changes in: ► Physical activity and dietary behaviour.
	Organisational: Eastern Cape Department of Education Nelson Mandela University	Number and characteristics of: ► Schools/districts that have the intervention integrated into the curriculum/environment. ► Actions taken towards its permanent integration (policy), for example, teaching agenda of future educators.

RE-AIM, Reach, Efficacy, Adoption, Implementation, Maintenance.

outcome with the same random effects structure and the same predictor variables, as previously described, for the mixed linear models. Additional analyses will be conducted by treating the postintervention and the two consequent FU outcomes as repeated measures.

To adjust for biases associated with missing data and/or lost to follow-up, inverse probability weighting will be used. Data imputation will be considered as an additional option if the drop-out rate is moderate (<20%).

Impact analysis

For the second objective of assessing the overall community impact of the intervention, its acceptability, adoption, implementation and maintenance will be explored at the individual, community and organisational level. For this purpose, a systematic analysis will be performed based on the RE-AIM evaluation framework and its proposed dimensions ((1) Reach, (2) Efficacy, (3) Adoption, (4) Implementation and (5) Maintenance).[50] Each dimension will be analysed separately, using pieces of data collected by the above-mentioned methods and as described in table 2, and results will be expressed as percentages. Ultimately, the combination of all five dimensions will result in a score that Glasgow and colleagues refer to as «public health impact» or «population-based effect».[50]

Participant and public involvement

Adult participants were involved in the conception of the research question by identifying their pivotal role in both the implementation and maintenance of the intervention. They will collaborate in the methodology via interviews and FGDs, where preliminary results will be presented for their verification. Participants will also contribute to the results by reporting on the burden of the interventions and specific local needs.

Participants have been informed on the study, alongside their right to voluntary participation and withdrawal at any time without justification. Before taking part in any assessment, as proposed by this study, oral assent has been sought from children and written consent from their guardians, as well as from the participating educators.

Study results will be summarised in manuscripts and submitted for publication to open-access, peer-reviewed scientific journals. Results will also be presented at relevant national and international conferences and workshops.

Methodological limitations

The implementation of *KaziKidz* and *KaziHealth* will not be monitored by the research team and schools were given the freedom to decide whether, and to what extent, they will deliver the health interventions. Therefore, any participating school may decide not to implement the interventions after completion of the *KaziBantu* trial. The extent of *KaziKidz*'s implementation will be assessed via questionnaire with school representatives and information about the reasons for discontinuation will be sought; this information will be considered for the feasibility assessment. Similarly, the status and extent, including reasons for discontinuation, of *KaziHealth*'s implementation will also be explored and evaluated via FGDs with school educators, headmasters' and ECDoE officials. Furthermore, for those cases where a further implementation of the interventions has not taken place, it will be aimed at measuring the corresponding children and educators at the foreseen follow-up time points.

Discussion

Globally, a total of 41 million deaths are attributable to non-communicable, chronic conditions, such as diabetes, coronary heart diseases or cancer every year. Of those deaths, it is estimated that around 80% are preventable because they are associated with poor diets, physical inactivity, alcohol addiction, tobacco use and polluted environments. However, NCD aetiology is very complex and individuals cannot be held responsible because they live in a system that encourages unhealthy behaviours. Hence, aiming merely to change behaviours might be complicated and ineffective over time. Instead, the focus should be on tailoring interventions aimed at creating environments that promote healthy lifestyles, making the system more beneficial, accessible and affordable for everyone. This is especially important in the early stages of life, where healthy behaviours can be adopted naturally and maintained throughout life. Furthermore, NCDs are a major threat to individual and national economic development: unhealthy habits acquired during childhood will most likely lead to unhealthy adults who are unable to develop to their full potential.[51]

The COVID-19 pandemic has highlighted the increased risk for severe disease and mortality faced by people living with chronic conditions.[52] At the same time, it has jeopardised the livelihood of millions of families, disproportionately hitting the most vulnerable and taking a special toll on children.[53] By December 2020, South African children lost up to a third of the school year, thus, not being able to complete the entire curriculum and leaving many gaps in children's education. Moreover, socioeconomic inequality is also likely to have further increased, since poorer learners and schools were least able to catch up.[54]

On reopening in both 2020 and 2021, schools in South Africa have been forced to adopt strict measures to further limit the spread of COVID-19. In addition to the staggered return to the school system, the 1.5 m social distancing requirement has led to schools incorporating what they referred to as a block teaching system, whereby schools operate at 50% or less of their capacity. More information on COVID-19-related school lockdown and closure in South Africa and the Gqeberha region can be found in online supplemental material. Furthermore, the ECDoE advised schools not to exclude any of the subjects from the curriculum, but to prioritise the more heavily weighted academic subjects, such as English, Afrikaans, Mathematics and Science. Physical education is currently not a stand-alone subject in the South African curriculum but forms part of the Life Orientation/Life Skills subject. Consequently, the likelihood of physical education receiving limited attention, and even being neglected, throughout the COVID-19 pandemic is high. Hence, we believe that the implementation of the *KaziKidz* material might have been affected too, which justifies further exploration. The complexity of lifestyle interventions, such as *KaziKidz* and *KaziHealth,* and their successful implementation reside in their multidimensional nature, that is, the involvement of individual, environmental and policy factors that interact at multiple social levels (individual, community and organisational institutional). The RE-AIM framework will be followed to predict the feasibility of both interventions in terms of effectiveness, addressing whole populations, being long-lasting and becoming institutionalised.[50 55 56] The information obtained from linking the intervention integration level in the schools with the personal adoption of behavioural changes and the achieved health effects both in children and educators, will yield unprecedented results on lifestyle interventions' potential to effectively promote the acquisition and maintenance of healthy lifestyles during childhood and adulthood that will ultimately support overall community health and well-being. Furthermore, we believe that continuing with the assessments indicated in the methodology sections will provide valuable insights into the children's health amidst the COVID-19 pandemic, and facilitate contextually valid recommendations for future interventions, policy and practice.

Finally, due to the multifactorial nature of NCDs, collaboration among different sectors, such as governments, communities, academia and the private sector, is necessary. The comprehensive evaluation of a tailored school-based health promotion intervention presented in this paper could provide unique evidence and support the dissemination of the intervention and collaboration between partners from different sectors,[57] ultimately influencing local policy.[58]

Author affiliations
[1]Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland

[2]Department of Human Movement Science, Nelson Mandela Metropolitan University, Gqberha, South Africa
[3]Swiss Tropical and Public Health Institute, Basel, Switzerland
[4]University of Basel, Basel, Switzerland
[5]Department of Social Sciences, University of Basel, Basel, Switzerland
[6]Centre for Community Technologies, Nelson Mandela Metropolitan University, Gqberha, South Africa

Acknowledgements The research team would like to thank Dr Bruce Damons (Director of Centre for the Community School, Nelson Mandela University, Gqeberha) for acting as an advisor on the project and being a key intermediary between the universities and the schools. We would also like to thank PD Dr Christian Schindler, who provided input for the statistical analysis of the study. This study takes place under the auspices of the UNESCO Chair on *'Physical Activity and Health in Educational Settings*'.

Contributors PA, LA and IM conceptualised the study and led the development of the general project. MG, UP, CW, RdR, PS, DvG and JU contributed to the development of the study design and methodology. MMB and HS provided statistical input and developed the draft data analysis plan. PA and LA drafted this manuscript, PA elaborated the KaziKidz's part, while LA contributed with the KaziHealth's fraction. All coauthors commented on revised drafts and approved the final version of the manuscript.

Funding This study is funded by the Swiss National Science Foundation (SNF; Bern, Switzerland; project no. 320030_192651).

Competing interests All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: PA and UP received financial support from the SNF for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Patient consent for publication Not applicable.

Ethics approval The proposed research will be carried out according to the international ethical, scientific and clinical practice standards established in the Declaration of Helsinki, gathered in the International Conference on Harmonisation (ICH) Guidelines, and encouraged by WHO. Prior to study conduct, ethical approval was granted by the Nelson Mandela University Research Ethics Committee (ref. no. H20-HEA-HMS-001; 21/07/2020), the Ethics Committee Northwest and Central Switzerland (EKNZ; ref. no. Req-2020–00430; 12/05/2020) and the Eastern Cape Department of Education (07/12/2020).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement No data are available.

Author note Joint first authorship: PA and LA contributed equally to this manuscript.

ORCID iDs
Patricia Arnaiz http://orcid.org/0000-0001-5626-3510
Markus Gerber http://orcid.org/0000-0001-6140-8948
Peter Steinmann http://orcid.org/0000-0003-4800-3019

REFERENCES

1 Blair DM, Stewart-Brown PS, Waterston DT. *Child public health*, 2010.
2 Steinmann P, Usubalieva J, Imanalieva C, *et al*. Rapid appraisal of human intestinal helminth infections among schoolchildren in OSH Oblast, Kyrgyzstan. *Acta Trop* 2010;116:178–84.
3 Victora CG, Adair L, Fall C, *et al*. Maternal and child undernutrition: consequences for adult health and human capital. *Lancet* 2008;371:340–57.
4 Dewey KG, Begum K. Long-term consequences of stunting in early life. *Matern Child Nutr* 2011;7 Suppl 3:5–18.
5 Zar HJ, Dawa J, Fischer GB, *et al*. Challenges of COVID-19 in children in low- and middle-income countries. *Paediatr Respir Rev* 2020;35:70–4.
6 NCD Risk Factor Collaboration (NCD-RisC). Rising rural body-mass index is the main driver of the global obesity epidemic in adults. *Nature* 2019;569:260–4.
7 Gouda HN, Charlson F, Sorsdahl K, *et al*. Burden of non-communicable diseases in sub-Saharan Africa, 1990-2017: results from the global burden of disease study 2017. *Lancet Glob Health* 2019;7:e1375–87.
8 Lozano R, Naghavi M, Foreman K, *et al*. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the global burden of disease study 2010. *Lancet* 2012;380:2095–128.
9 Lim SS, Vos T, Flaxman AD, *et al*. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. *The Lancet* 2012;380:2224–60.
10 Murray CJL, Vos T, Lozano R, *et al*. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the global burden of disease study 2010. *The Lancet* 2012;380:2197–223.
11 Steyn NP, McHiza ZJ. Obesity and the nutrition transition in sub-Saharan Africa. *Ann N Y Acad Sci* 2014;1311:88–101.
12 Moselakgom VK, Staden MV. Physical activity and risk factors of cardio-metabolic diseases in South African children. *Asian J Sci Res* 2018;11:498–505.
13 Berenson GS, Srinivasan SR, Bao W, *et al*. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. The Bogalusa heart study. *N Engl J Med* 1998;338:1650–6.
14 Joshi SM, Katre PA, Kumaran K, *et al*. Tracking of cardiovascular risk factors from childhood to young adulthood - the Pune children's study. *Int J Cardiol* 2014;175:176–8.
15 Yawson AE, Abuosi AA, Badasu DM, *et al*. Non-communicable diseases among children in Ghana: health and social concerns of parent/caregivers. *Afr Health Sci* 2016;16:378–88.
16 WHO. Global strategy on diet. In: *Physical activity and health*, 2004.
17 Walter CM. In-school physical activity patterns of primary school learners from disadvantaged schools in South Africa. *African Journal for Physical, Health Education, Recreation and Dance* 2011;17:780–9.
18 Draper CE, Tomaz SA, Harbron J, *et al*. Results from the healthy active kids South Africa 2018 report card. *S Afr J CH* 2018;13:130–6.
19 Puder JJ, Marques-Vidal P, Schindler C, *et al*. Effect of multidimensional lifestyle intervention on fitness and adiposity in predominantly migrant preschool children (ballabeina): cluster randomised controlled trial. *BMJ* 2011;343:d6195.
20 Wilson DK, Van Horn ML, Kitzman-Ulrich H, *et al*. Results of the "active by choice today" (ACT) randomized trial for increasing physical activity in low-income and minority adolescents. *Health Psychol* 2011;30:463–71.
21 Lambrinou C-P, Androutsos O, Karaglani E, *et al*. Effective strategies for childhood obesity prevention via school based, family involved interventions: a critical review for the development of the feel4diabetes-study school based component. *BMC Endocr Disord* 2020;20:52.
22 Draper CE, de Villiers A, Lambert EV, *et al*. HealthKick: a nutrition and physical activity intervention for primary schools in low-income settings. *BMC Public Health* 2010;10:398.
23 de Villiers A, Steyn NP, Draper CE, *et al*. Implementation of the HealthKick intervention in primary schools in low-income settings in the Western Cape Province, South Africa: a process evaluation. *BMC Public Health* 2015;15:818.
24 Blaine RE, Franckle RL, Ganter C, *et al*. Using school staff members to implement a childhood obesity prevention intervention in low-income school districts: the Massachusetts childhood obesity research demonstration (MA-CORD project), 2012-2014. *Prev Chronic Dis* 2017;14:E03.

25 Gorely T, Nevill ME, Morris JG, *et al*. Effect of a school-based intervention to promote healthy lifestyles in 7-11 year old children. *Int J Behav Nutr Phys Act* 2009;6:5.
26 Rosário R, Oliveira B, Araújo A, *et al*. The impact of an intervention taught by trained teachers on childhood overweight. *Int J Environ Res Public Health* 2012;9:1355–67.
27 Innerd AL, Azevedo LB, Batterham AM. The effect of a curriculum-based physical activity intervention on accelerometer-assessed physical activity in schoolchildren: a non-randomised mixed methods controlled before-and-after study. *PLoS One* 2019;14:e0225997.
28 Gerber M, Müller I, Walter C, *et al*. Physical activity and dual disease burden among South African primary schoolchildren from disadvantaged neighbourhoods. *Prev Med* 2018;112:104–10.
29 Müller I, Schindler C, Adams L, *et al*. Effect of a multidimensional physical activity intervention on body mass index, skinfolds and fitness in South African children: results from a cluster-randomised controlled trial. *Int J Environ Res Public Health* 2019;16. doi:10.3390/ijerph16020232. [Epub ahead of print: 15 01 2019].
30 Müller I, Smith D, Adams L, *et al*. Effects of a school-based health intervention program in marginalized communities of port elizabeth, South Africa (the KaziBantu study): protocol for a randomized controlled trial. *JMIR Res Protoc* 2019;8:e14097.
31 Kivimäki M, Leino-Arjas P, Luukkonen R, *et al*. Work stress and risk of cardiovascular mortality: prospective cohort study of industrial employees. *BMJ* 2002;325:857.
32 Peltzer K, Shisana O, Zuma K, *et al*. Job stress, job satisfaction and stress-related illnesses among South African educators. *Stress and Health* 2009;25:247–57.
33 Sarrafzadegan N, Kelishadi R, Esmaillzadeh A, *et al*. Do lifestyle interventions work in developing countries? findings from the Isfahan healthy heart program in the Islamic Republic of Iran. *Bull World Health Organ* 2009;87:39–50.
34 Gerber M, Fuchs R, Pühse U. Follow-Up of a short motivational and volitional exercise-intervention trial with overweight and obese individuals. *Schweizerische Zeitschrift für «Sportmedizin und Sporttraumatologie»* 2010;58:108–14.
35 Sarrafzadegan N, Rabiei K, Wong F, *et al*. The sustainability of interventions of a community-based trial on children and adolescents' healthy lifestyle. *ARYA Atheroscler* 2014;10:107–17.
36 Nguyen S, Häcker A-L, Henderson M, *et al*. Physical activity programs with Post-Intervention follow-up in children: a comprehensive review according to categories of intervention. *Int J Environ Res Public Health* 2016;13. doi:10.3390/ijerph13070664. [Epub ahead of print: 30 06 2016].
37 UNESCO Chair on Physical Activity and Health in Educational Settings. KaziBantu project and teaching materials, 2019. Available: https://kazibantu.org/ [Accessed 13 Sep 2020].
38 Kowalski KC, Crocker PRE, Donen RM. *The physical activity questionnaire for older children (PAQ-C) and adolescents (PAQ-A) manual*. Saskatchewan Uo, 2004.
39 Kruger R, Monyeki MA, Schutte AE, *et al*. The exercise, arterial modulation and nutrition in youth South Africa study (ExAMIN youth SA). *Front Pediatr* 2020;8:212.
40 WHO. *Global Health Survey (GHS)_Core Modules*, 2013.
41 Shim J-S, Oh K, Kim HC. Dietary assessment methods in epidemiologic studies. *Epidemiol Health* 2014;36:e2014009.
42 The European KIDSCREEN Group. The KIDSCREEN-10 index: health-related quality of life questionnaire for children and adolescents aged from 8 to 18 years, 2011. Available: https://www.kidscreen.org/english/questionnaires/kidscreen-10-index/ [Accessed 13 Sep 2020].
43 Ravens-Sieberer U, Erhart M, Rajmil L, *et al*. Reliability, construct and criterion validity of the KIDSCREEN-10 score: a short measure for children and adolescents' well-being and health-related quality of life. *Qual Life Res* 2010;19:1487–500.
44 Reis RS, Hino AAF, Añez CRR. Perceived stress scale: reliability and validity study in Brazil. *J Health Psychol* 2010;15:107–14.
45 Zurlo MC, Pes D, Siegrist J. Validity and reliability of the effort-reward imbalance questionnaire in a sample of 673 Italian teachers. *Int Arch Occup Environ Health* 2010;83:665–74.
46 Pujol-Cols L. Development and validation of the spanish work-family conflict scale (SP-WFCS): evidence from two independent samples in Argentina. *Curr Psychol* 2021;40:4189–204.
47 İ Ülbeği, İplik E. The reliability and validity of the shirom-melamed burnout measure. *Cag University Journal of Social Sciences* 2017;14:19–30.
48 Forero R, Nahidi S, De Costa J, *et al*. Application of four-dimension criteria to assess rigour of qualitative research in emergency medicine. *BMC Health Serv Res* 2018;18:120.
49 Hsieh H-F, Shannon SE. Three approaches to qualitative content analysis. *Qual Health Res* 2005;15:1277–88.
50 Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health* 1999;89:1322–7.
51 Craigie AM, Lake AA, Kelly SA, *et al*. Tracking of obesity-related behaviours from childhood to adulthood: a systematic review. *Maturitas* 2011;70:266–84.
52 WHO. Responding to non-communicable diseases during and beyond the Covid-19 pandemic 2020.
53 Min Y, Perucci F. *Impact of COVID-19 on SDG progress: a statistical perspective*. 5. United Nations, 2020.
54 Spaull N, Van der Berg S. Counting the cost: COVID-19 school closures in South Africa and its impact on children. *South African Journal of Childhood Education* 2020;10.
55 Gaglio B, Shoup JA, Glasgow RE. The RE-AIM framework: a systematic review of use over time. *Am J Public Health* 2013;103:e38–46.
56 Lew MS, L'Allemand D, Meli D, *et al*. Evaluating a childhood obesity program with the reach, effectiveness, adoption, implementation, maintenance (RE-AIM) framework. *Prev Med Rep* 2019;13:321–6.
57 Naylor P-J, Nettlefold L, Race D, *et al*. Implementation of school based physical activity interventions: a systematic review. *Prev Med* 2015;72:95–115.
58 Singh A, Bassi S, Nazar GP, *et al*. Impact of school policies on non-communicable disease risk factors - a systematic review. *BMC Public Health* 2017;17:292.
59 World Health Organization. Growth reference data for 5-19 years: BMI-for-age, 2007. Available: https://www.who.int/growthref/who2007_bmi_for_age/en/ [Accessed 13 Sep 2020].
60 de Onis M, Onyango AW, Borghi E, *et al*. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007;85:660–7.
61 Rosner B, Cook N, Portman R, *et al*. Determination of blood pressure percentiles in normal-weight children: some methodological issues. *Am J Epidemiol* 2008;167:653–66.
62 Flynn JT, Kaelber DC, Baker-Smith CM, *et al*. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. *Pediatrics* 2017;140:e20171904.
63 American Diabetes Association. 2. Classification and diagnosis of diabetes: standards of medical care in diabetes-2020. *Diabetes Care* 2020;43:S14–31.
64 National cholesterol education program (NCEP): highlights of the report of the expert panel on blood cholesterol levels in children and adolescents. *Pediatrics* 1992;89:495.
65 Expert panel on integrated guidelines for cardiovascular H, risk reduction in C, adolescents, National heart L, blood I. expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: summary report. *Pediatrics* 2011;128:S213–56.

Chapter 6. Publication 4

Intervention effects and long-term changes in physical activity and cardiometabolic outcomes among children at risk of noncommunicable diseases in South Africa: a cluster-randomized controlled trial and follow-up analysis

Patricia Arnaiz[1], Harald Seelig[1], Markus Gerber[1], Larissa Adams[2], Jan Degen[1], Danielle Dolley[2], Nandi Joubert[1,3,4], Madeleine Nienaber[2], Siphesihle Nqweniso[2], Peter Steinmann[3,4], Jürg Utzinger[3,4], Rosa du Randt[2], Cheryl Walter[2], Uwe Pühse[1], Ivan Müller[1]

[1]Department of Sport, Exercise and Health, University of Basel, 4052 Basel, Switzerland.

[2]Department of Human Movement Science, Nelson Mandela University, 6031 Gqeberha, South Africa.

[3]Swiss Tropical and Public Health Institute, 4002 Basel, Switzerland.

[4]University of Basel, 4001 Basel, Switzerland.

Published in:

Frontiers in Public Health. 2023; 11:1199381.

The final publication is available at: https://doi.org/10.3389/fpubh.2023.1199381.

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 26 May 2023
DOI 10.3389/fpubh.2023.1199381

OPEN ACCESS

EDITED BY
Graça S. Carvalho,
University of Minho, Portugal

REVIEWED BY
Margarida Vieira,
University of Minho, Portugal
Natasha Sobers,
The University of the West Indies, Cave Hill, Barbados

*CORRESPONDENCE
Patricia Arnaiz
✉ patricia.arnaiz@unibas.ch

RECEIVED 03 April 2023
ACCEPTED 12 May 2023
PUBLISHED 26 May 2023

CITATION
Arnaiz P, Seelig H, Gerber M, Adams L, Degen J, Dolley D, Joubert N, Nienaber M, Nqweniso S, Steinmann P, Utzinger J, du Randt R, Walter C, Pühse U and Müller I (2023) Intervention effects and long-term changes in physical activity and cardiometabolic outcomes among children at risk of noncommunicable diseases in South Africa: a cluster-randomized controlled trial and follow-up analysis.
Front. Public Health 11:1199381.
doi: 10.3389/fpubh.2023.1199381

Intervention effects and long-term changes in physical activity and cardiometabolic outcomes among children at risk of noncommunicable diseases in South Africa: a cluster-randomized controlled trial and follow-up analysis

Patricia Arnaiz[1]*, Harald Seelig[1], Markus Gerber[1], Larissa Adams[2], Jan Degen[1], Danielle Dolley[2], Nandi Joubert[1,3,4], Madeleine Nienaber[2], Siphesihle Nqweniso[2], Peter Steinmann[3,4], Jürg Utzinger[3,4], Rosa du Randt[2], Cheryl Walter[2], Uwe Pühse[1] and Ivan Müller[1]

[1]Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland, [2]Department of Human Movement Science, Nelson Mandela University, Gqeberha, South Africa, [3]Swiss Tropical and Public Health Institute, Allschwil, Switzerland, [4]University of Basel, Basel, Switzerland

Introduction: Risk factors for noncommunicable diseases such as insufficient physical activity (PA), overweight or hypertension are becoming increasingly predominant among children globally. While school-based interventions are promising preventive strategies, evidence of their long-term effectiveness, especially among vulnerable populations, is scarce. We aim to assess the short-term effects of the physical and health *KaziKidz* intervention on cardiometabolic risk factors and the long-term, pre-and post-COVID-19 pandemic changes thereof in high-risk children from marginalized communities.

Methods: The intervention was tested in a cluster-randomized controlled trial between January and October 2019 in eight primary schools near Gqeberha, South Africa. Children with overweight, elevated blood pressure, pre-diabetes, and/or borderline dyslipidemia were identified and re-assessed 2years post-intervention. Study outcomes included accelerometry-measured PA (MVPA), body mass index (BMI), mean arterial pressure (MAP), glucose (HbA1c), and lipid levels (TC to HDL ratio). We conducted mixed regression analyses to assess intervention effects by cardiometabolic risk profile, and Wilcoxon signed-rank tests to evaluate longitudinal changes in the high-risk subpopulation.

Results: We found a significant intervention effect on MVPA during school hours for physically inactive children, and among active as well as inactive girls. In contrast, the intervention lowered HbA1c and TC to HDL ratio only in children with glucose or lipid values within the norm, respectively. At follow-up, the intervention effects were not maintained in at-risk children, who showed a decline in MVPA, and an increase in BMI-for-age, MAP, HbA1c and TC to HDL ratio.

Conclusion: We conclude that schools are key settings in which to promote PA and improve health; however, structural changes are necessary to ensure that effective interventions reach marginalized school populations and achieve sustainable impact.

KEYWORDS

physical activity, health promotion, school-based, noncommunicable diseases, effectiveness, sustainability, South Africa

1. Introduction

Unhealthy behaviors, such as physical inactivity, and subsequent cardiometabolic changes including increased weight, raised blood pressure (BP), high plasma glucose, or an abnormal lipid profile are well-established risk factors for noncommunicable diseases (NCDs) diseases (1). While NCDs appear typically in adulthood, evidence shows that health during the first periods of life will have an impact on adult life (2). Yet, modifiable risk factors are getting more predominant among children. For instance, it is estimated that 81% of children worldwide do not meet the recommended 60 min of moderate to vigorous intensity physical activity (MVPA) per day (3). Meanwhile, childhood obesity and hypertension have increased dramatically in the last decades (4, 5). Hence, reducing risk factors early in life to prevent the continuous rise of NCDs is urgently needed.

One strategy to halt the incidence of NCDs is promoting healthy, active lifestyles from a young age (6). Engagement in regular physical activity (PA) has been described to support physical and mental health in school-aged children and avert weight-related cardiometabolic diseases (7–10). At the same time, education to support behavioral change around PA has been recognized as a cost-effective strategy to reduce NCDs (11). Thus, several PA interventions have focused on the school setting for this purpose. Concretely, comprehensive school PA programs (CSPAs) have been identified as promising strategies to increase daily movement while reaching vast numbers of children (12).

However, conflicting literature exists about the effectiveness of school-embedded programs in increasing PA and improving health among children. Systematic reviews have demonstrated either no improvement in PA and cardiovascular risk (13, 14), or positive though modest effects (15, 16) both in the short- and long-term. Although initial beneficial effects have been described to attenuate over time, more complex interventions that showed no immediate impact reported improvements long after the intervention's end (17). Thus, follow-up measurements are important to evaluate the efficacy of interventions and maintenance of results.

Furthermore, the majority of evidence originates from high-income countries. In South Africa, varying results have been described for school-based interventions on health behaviors and risk among underprivileged adolescents (18, 19). A recent systematic review corroborated the inconsistency in interventions effectiveness in Africa (20). On the other hand, studies have shown that tailoring programs to the needs of vulnerable groups rather than prioritizing a higher population reach, increases intervention feasibility (21). The scarcity of evidence and discrepant results highlight the need for further research on the long-term effectiveness of lifestyle interventions in low- to middle-income countries, especially among vulnerable groups.

Against this background, we developed the *KaziKidz* health promotion program incorporating CSPAs components and tailoring it to low-resourced schools.[1] The main purpose of this study is to examine short- and long-term changes on the cardiometabolic risk profile of children at risk of NCDs as a result of program participation. Specifically, we will first compare children presenting risk factors for NCDs with healthy counterparts, and assess the intervention effect on movement and cardiometabolic parameters. We will then examine the development of these risk factors in at-risk children two years' post-intervention. Based on prior knowledge, we hypothesize that the intervention will have a positive effect on improving learners' health outcomes, but we expect the effect to decline over time.

2. Materials and methods

2.1. Study design

A cluster-randomized controlled trial (RCT) was implemented in low-income primary schools from marginalized neighborhoods around Gqeberha, in the Eastern Cape of South Africa (22). The study included baseline assessments in January 2019, a 20 week intervention period, and post-intervention measurements in October 2019. Eight schools met the inclusion criteria of geographical location and representativeness, language, and school commitment. The allocation to a study condition was done at the school level, in a sequential manner, and using opaque, sealed envelopes. Four schools were randomly allotted to the intervention arm, and four to the control arm.

Building on the RCT, a cohort of at-risk children was identified and followed up two years' post-intervention with a final assessment in October 2021.

2.2. Intervention

The *KaziKidz* intervention is part of the *KaziBantu* project that aims to enhance health and physical literacy in low-resourced primary schools. It utilizes the *KaziKidz* toolkit, which consists of ready-to-use lessons for teachers covering (1) physical education (PE), (2) moving-to-music dance classes, and (3) health, hygiene and nutrition education. PE and moving-to-music each comprise 32 lessons of 40 min, with one weekly lesson of each subject. Health and hygiene,

1 https://www.kazibantu.org/

and nutrition each include three 40 min lessons conducted throughout the school year. All lessons are adapted for grades one to seven.

The *KaziKidz* teaching material was delivered to all classes grades four to six from March to July 2019 by life-skills orientation teachers. In addition, the four intervention schools received basic sports equipment and painted playground games. To test different delivery strategies, two of these schools were additionally offered two 90 min workshops that informed teachers on the practical implementation of the toolkit. One of them further received support from a trained sports graduate from the Department of Human Movement Science at the Nelson Mandela University, who assisted teachers with the intervention delivery.

Further details on the intervention can be found in the study protocol (22).

2.3. Participants

In the original RCT, data was collected from one class of each grade (grades four to six) in all participating schools, with most children being 8–13 years old. For a child to participate in the RCT, the following inclusion criteria had to be met: (1) having written consent from a guardian and oral assent from child, (2) not been enrolled in other clinical trials, and (3) have been cleared to participate by a qualified healthcare professional.

As reported in the first section of the flow diagram (Figure 1), 1,020 learners were screened and 975 randomized at school level after having met the inclusion criteria. Excluding baseline and post-intervention drop-outs, data from 961 learners (473 intervention versus 488 control arm) were included in the short-term analysis.

For the follow-up study, a sub-cohort of children was selected and included in the study if they (1) had participated in the RCT baseline and post-intervention assessments; (2) based on the baseline records presented at least one of the following cardiometabolic diseases: (i) overweight or obesity, (ii) elevated BP or hypertension, (iii) pre-diabetes or diabetes, (iv) borderline or dyslipidemia, based on age-standardized guidelines; and (3) had given consent. The second section of Figure 1 shows that from an eligible sample of 543 children identified at risk, 280 were enrolled in the study and included in the final analysis (133 intervention versus 147 control arm). Further details on the study population and setting can be found in the study protocols (22, 23).

2.4. Data collection

2.4.1. Physical activity

PA was assessed via accelerometry. The triaxial actigraph wGT3X-BT (ActiGraph LLC, Pensacola, United States) was set up at a 30 Hz sampling rate and worn around the hip for seven consecutive days. Data processing was done in the ActiLife software (version 6.13.4; ActiGraph LLC, Pensacola, United States) using a 10 s epoch length and the Troiano et al. algorithm to remove non-wear-time (24). PA measurements were included for further analyses if they consisted of at least three valid schooldays and one valid weekend day. A valid day was defined by a minimum of three hours' wear-time between 08:00 and 15:00 (school days), or eight hours between 06:00 and 24:00 (weekend day). MVPA was calculated as minutes per day spent in moderate and vigorous intensity activity levels, as defined by Evenson et al. cut-off points. Non-compliance with the 60 min of MVPA per day recommended for children by the World Health Organization (WHO) was considered physical inactivity.

2.4.2. Anthropometric and clinical outcomes

We used a digital weighing scale (MC-580; Tanita, Tokyo, Japan) to measure body weight and a stadiometer for body height. Body mass index represents weight (kg) divided by squared height (m^2). Sex-adjusted BMI-for-age *z* scores (zBMI) were determined based on the WHO children growth standards (25). Overweight was defined as zBMI values over 1 standard deviation.

Resting BP was appraised three times using the Omron automated oscillometric device (Omron® M6 AC; Hoofddorp, Netherlands). The mean of the last two readings was used to compute systolic (SBP) and diastolic (DBP) BP. Mean arterial blood pressure (MAP) was calculated as: 1/3(SBP-DBP) + DBP (26). A SBP and/or DBP over the 90th percentile or 120/80 mmHg were characterized as elevated BP (27).

Minimally invasive blood sampling was done by pricking the child's fingertip with a safety lancet. The Alere Afinion AS 100 Analyzer device (Abbott Laboratories, Illinois, United States) was used to determine glycated haemoglobin (HbA1c) and total cholesterol (TC) to high-density lipoprotein (HDL) ratio levels. HbA1c values higher than 39 mmol/mol and a TC higher than 4.40 mmol/L were indicative of pre-diabetes (28) and borderline dyslipidemia (29), respectively.

2.4.3. Socioeconomic status

We employed a nine-item questionnaire covering housing characteristics (type of house, number of bedrooms, own toilet, type of toilet, access to water, access to electricity) and household possessions (washing machine, refrigerator, car) to evaluate the socioeconomic status (SES) of children according to previous research (30). A SES index was calculated by dichotomizing the nine items (0 = not available, low quality; 1 = available, high quality) and adding them up, whereby 0 represents the lowest SES possible and 9 the highest.

2.5. Statistical analyses

Data was double-entered and validated using EpiData (version 3.1), and EvaSys (version 7.1) was used to appraise questionnaire data. Continuous outcomes were described with medians and 95% confidence intervals (CI), while categorical variables were presented as frequencies and 95% CI. Since missing data differed by outcome, we reported sample size for each analysis separately. We applied a series of separate linear mixed models to evaluate the short-term intervention effect on PA and health outcomes by risk group using classes as random effects. Model for zBMI-for-age was controlled for baseline levels and SES. Models for MAP, HbA1c and TC to HDL ratio were controlled for baseline levels, age, sex, and SES. Total and school MVPA were controlled for baseline levels, age, sex, SES, and wear-time. Post-hoc analyses included studying the effect of the intervention on PA levels by sex. To assess the long-term development of cardiovascular risk factors in the subsample of at-risk children, we performed pair-wise Wilcoxon signed-rank tests

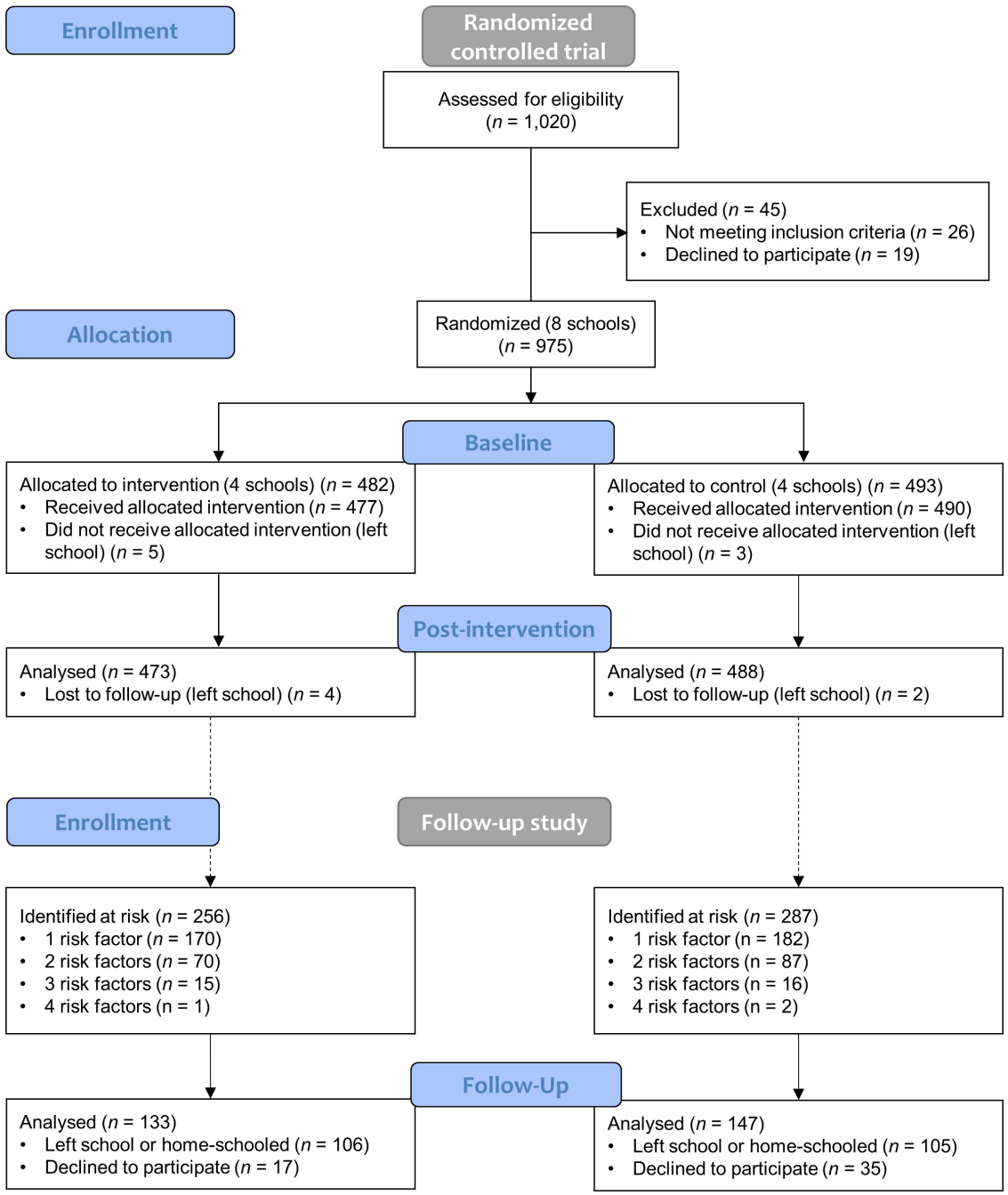

FIGURE 1
Participant flow diagram.

for within-subject variations between baseline, post-intervention and follow-up. Size effect r was calculated as the absolute z score divided by the square root of the sample size, and interpreted according to Cohen (31). We then conducted the mixed linear regression models described above to examine the association between intervention arm and long-term outcomes. We used the bias-corrected and accelerated bootstrap interval with 1,000 replicates to construct estimates and 95% CI, and we set a significance level at $p < 0.05$ for all analyses. Statistical analyses were done in IBM SPSS Statistics (version 28) for Windows.

3. Results

Table 1 shows baseline characteristics of all participants by intervention group. Median age was 10.8 years old (95% CI: 10.71 to 10.92) and the percentage of girls and boys was distributed almost equally between both the intervention and the control group (girls: 49.0% versus 48.8%; boys: 51.0% versus 51.2%, respectively). Median SES was 6.0 (95% CI: 6.00 to 6.00) for both groups. The control and the intervention groups differed in MAP (Md: 80.67 versus 79.00, respectively) and TC to HDL ratio (Md: 3.00 versus

10.3389/fpubh.2023.1199381

TABLE 1 Demographic and clinical characteristics of participants at baseline, in January 2019 (*N*=961).

Numeric variable	Control			Intervention		
	N	Median	95% CI	*N*	Median	95% CI
Age (years)	488	10.88	10.72–11.02	473	10.73	10.61–10.89
Total MVPA[a] (min/day)	466	67.82	64.61–71.42	449	71.93	68.17–74.24
In-school MVPA (min/day)	466	16.26	15.33–17.20	449	16.60	15.93–17.50
BMI[b]-for-age (*z* scores)	443	0.15	0.00–0.28	469	−0.12	−0.23–0.01
MAP[c] (mmHg)	478	**80.67**	**79.67–81.50**	460	**79.00**	**78.17–79.67**
HbA1c[d] (mmol/mol)	364	36.00	35.00–36.00	395	36.00	35.00–36.00
TC:HDL[e]	357	**3.00**	**2.90–3.10**	394	**2.80**	**2.70–2.90**
SES[f] (0–9 scale)	454	6.00	6.00–7.00	435	6.00	6.00–6.00
Categorical variable	**Control**			**Intervention**		
	N	%	95% CI	*N*	%	95% CI
Sex						
Girls	238	48.8	44.5–53.3	232	49.0	44.4–53.7
Boys	250	51.2	46.7–55.5	241	51.0	46.3–55.6
Physical inactivity[g]	176	37.8	33.5–42.3	152	33.9	29.8–38.3
Overweight[h]	113	25.5	21.2–29.8	91	19.4	15.8–22.8
Elevated blood pressure[i]	183	38.3	33.9–42.5	161	35.0	30.7–39.6
Prediabetes[j]	50	13.7	10.4–17.3	53	13.4	10.1–16.7
Predyslipidemia[k]	66	18.5	14.6–22.7	54	13.7	10.2–17.3

[a]Moderate to vigorous intensity physical activity.
[b]Body mass index.
[c]Mean arterial pressure.
[d]Glycated haemoglobin.
[e]Total cholesterol to high-density lipoprotein ratio.
[f]Socioeconomic status.
[g]MVPA below 60 min a day.
[h]zBMI-for-age over 1 standard deviation.
[i]Systolic and/or diastolic blood pressure over the 90th percentile or 120/80 mmHg.
[j]HbA1c over 39 mmol/mol.
[k]TC over 4.40 mmol/L.
Bold values indicate statistical significance.

2.80, respectively). The prevalence of risk factors for all participants was 22.4% (95% CI: 19.7 to 25.2%) for overweight or obesity, 36.7% (95% CI: 33.6 to 39.8%) for elevated BP or hypertension, 13.6% (95% CI: 11.1 to 16.2%) for pre- or diabetes, 16.0% (95% CI: 13.2 to 18.6%) for pre- or dyslipidemia, and 35.8% (95% CI: 32.7 to 39.3) for physical inactivity.

Results of mixed regression analyses are presented in Table 2. The intervention showed a statistically significant effect in increasing MVPA during school among physically inactive children ($B = 1.71$, 95% CI: 0.14 to 3.35, $p = 0.008$) but not in already active children ($B = 0.19$, 95% CI: −1.58 to 1.08, $p = 0.762$). No significant intervention effect was observed for total MVPA in neither group. The intervention significantly lowered MAP both in children at risk of hypertension ($B = -2.16$, 95% CI: −4.20 to −0.06, $p = 0.008$) and in those not at risk ($B = -1.77$, 95% CI: −3.14 to −0.70, $p = 0.004$). For both HbA1c and TC to HDL ratio a significant positive intervention effect was observed in children not at risk of diabetes (HbA1c: $B = -0.26$, 95% CI: −0.52 to −0.01, $p = 0.037$) or dyslipidemia (TC to HDL ratio: $B = -0.11$, 95% CI: 0.18 to −0.05, $p = 0.002$). Meanwhile, children with higher HbA1c baseline levels did not experience a significant intervention effect ($B = -0.38$, 95% CI: −1.32 to 0.29, $p = 0.458$), while the intervention significantly increased TC to HDL ratio levels compared with those at baseline ($B = 0.12$, 95% CI: −0.002 to 0.23, $p = 0.036$).

The regression analysis showed a significant association of sex with total and in-school MVPA. Post-hoc analyses revealed that the intervention was effective in increasing in-school MVPA time among girls both not compliant ($B = 2.03$, 95% CI: 0.58 to 3.42, $p < 0.001$) and compliant ($B = 1.80$, 95% CI: −0.22 to 3.82, $p = 0.035$) with PA recommendations, but no significant association was observed for boys in either group ($B = 0.68$, 95% CI: −5.39 to 7.82, $p = 0.694$; $B = -1.39$, 95% CI: −3.29 to 0.50, $p = 0.109$, respectively), nor in total MVPA for any sub-group (Supplementary Table S1).

We report Wilcoxon signed-rank findings for within-subject variations over time in at-risk children in Table 3. In general, the test revealed a statistically significant change in all outcomes during the intervention period, and no significant change between post-intervention and follow-up. In physically inactive children, both total and in-school MVPA increased significantly ($z = -4.24$, $p < 0.001$; $z = -3.74$, $p < 0.001$, respectively) from baseline to post-intervention. From post-intervention to follow-up, the median

TABLE 2 Post- intervention effects on cardiometabolic risk factors in not at-risk versus at-risk children.

Risk factor	Not at-risk				At-risk			
	N	Beta	95% CI	*p*-value	*N*	Beta	95% CI	*p*-value
Total MVPA[a] (min/day)	425	−1.64	−5.94–2.66	0.314	254	0.70	−3.72–5.85	0.643
In-school MVPA (min/day)	425	−0.19	−1.58–1.08	0.762	253	**1.71**	**0.14–3.35**	**0.008**
BMI-for-age[b] (*z* scores)	646	−0.02	−0.07–0.03	0.336	186	−0.001	−0.09–0.11	0.981
MAP[c] (mmHg)	538	**−1.77**	**−3.14–−0.70**	**0.004**	317	**−2.16**	**−4.20–−0.06**	**0.008**
HbA1c[d] (mmol/mol)	600	**−0.26**	**−0.52–−0.01**	**0.037**	97	−0.38	−1.32–0.29	0.458
TC:HDL[e]	576	**−0.11**	**−0.18–−0.05**	**0.002**	111	**0.12**	**−0.002–0.23**	**0.036**

At-risk is defined for each outcome separately as: physical inactivity for total and in-school MVPA, overweight or obesity for BMI-for-age, elevated blood pressure or hypertension for MAP, pre- or diabetes for HbA1c, pre- or dyslipidemia for TC:HDL. Mixed linear regression were applied. All outcomes have been controlled for baseline outcome, age, sex and SES using class as random effects; BMI-for-age has not been controlled for age and sex; total and school MVPA have been further controlled for wear-time. Bias-corrected and accelerated (BCa) and 1,000 replicates bootstrap adjusted results.

[a]Moderate to vigorous intensity physical activity.

[b]Body mass index.

[c]Mean arterial pressure.

[d]Glycated haemoglobin.

[e]Total cholesterol to high-density lipoprotein ratio.

Bold values indicate statistical significance.

TABLE 3 Longitudinal changes in cardiometabolic risk factors in children at risk of noncommunicable diseases from baseline to follow-up.

Risk factor	*N*	Baseline	Post-intervention	Follow-up	Baseline—post-intervention			Post-intervention—follow-up		
		Median (95% CI)	Median (95% CI)	Median (95% CI)	*z*	*p*-value	*r*	*z*	*p*-value	*r*
Total MVPA[a] (min/day)	58	46.65 (45.71–48.60)	53.29 (49.40–57.26)	41.90 (38.40–53.31)	**−4.24**	**<0.001**	**0.56**	−1.95	0.052	0.26
In-school MVPA (min/day)	74	12.65 (11.50–15.03)	15.88 (14.13–17.93)	17.73 (15.53–19.47)	**−3.74**	**<0.001**	**0.43**	−1.45	0.147	0.17
BMI-for-age[b] (z scores)	101	1.76 (1.41–1.99)	1.77 (1.57–2.10)	1.82 (1.60–2.10)	**−2.07**	**0.039**	**0.21**	−0.34	0.737	0.03
MAP[c] (mmHg)	152	87.75 (86.08–89.50)	81.92 (80.58–83.83)	85.75 (84.25–87.50)	**−6.48**	**<0.001**	**0.53**	**−5.18**	**<0.001**	**0.42**
HbA1c[d] (mmol/mol)	43	39.00 (39.00–40.00)	37.00 (36.00–37.00)	38.00 (37.00–38.00)	**−5.78**	**<0.001**	**0.88**	−1.63	0.104	0.25
TC:HDL[e]	57	3.30 (3.00–3.50)	2.90 (2.70–3.30)	3.00 (2.80–3.20)	**−4.71**	**<0.001**	**0.62**	−1.61	0.11	0.21

At-risk is defined for each outcome separately as: below 60 min of MVPA a day for total and in-school MVPA, overweight or obesity for BMI-for-age, elevated blood pressure or hypertension for MAP, pre- or diabetes for HbA1c, pre- or dyslipidemia for TC:HDL. Wilcoxon signed-rank test. $r = z/\sqrt{N}$. Interpretation of size effect according to Cohen (1988): Small: *r* from 0.01 to 0.029. Medium: *r* from 0.30 to 0.49. Large: $r \geq 0.5$. Bias-corrected and accelerated (BCa) and 1,000 replicates bootstrap adjusted results.

[a]Moderate to vigorous intensity physical activity.

[b]Body mass index.

[c]Mean arterial pressure.

[d]Glycated haemoglobin.

[e]Total cholesterol to high-density lipoprotein ratio.

Bold values indicate statistical significance.

score of total MVPA declined from 53.29 to 41.90, although this decrease was not statistically significant ($z = -1.95$, $p = 0.05$) and of small effect size ($r = 0.26$). For in-school MVPA, a non-significant increase of small effect was observed at follow-up ($z = 1.45$, $p = 0.15$, $r = 0.17$). MAP was the only outcome that showed significant changes in both periods. While a significant decrease of large size effect was observed during the intervention ($z = -6.48$, $p < 0.001$, $r = 0.53$), MAP levels increased between post-intervention and follow-up ($z = -5.18$, $p < 0.001$) with a medium size effect ($r = 0.42$). Similarly, a statistically significant reduction of large size effect was observed from baseline to post-intervention in both HbA1c ($z = -5.78$, $p < 0.001$, $r = 0.88$) and TC to HDL ratio ($z = -4.71$, $p < 0.001$, $r = 0.62$), followed by a rise of the median values at follow-up that was non-significant and of small effect size (HbA1c: $z = -1.63$, $p = 0.104$, $r = 0.25$; TC to HDL ratio: $z = -1.61$, $p = 0.11$, $r = 0.21$). Median zBMI-for-age raised over time across all time points (Md: baseline: 1.76, post-intervention: 1.77, follow-up: 1.82).

Further, we wanted to examine whether an intervention effect could be observed in the long-term. Figure 2 depicts the development of cardiovascular risk factors in at-risk children from baseline to follow-up by intervention arm. For at-risk children who participated in the intervention, PA levels decreased between post-intervention and follow-up, and all other risk factors increased. Children at risk who were in the control group followed a similar development, except for school MVPA, whose levels rose during this period. We confirmed these observations via mixed regression analyses (Supplementary Table S2). No significant intervention effect was found between post-intervention and follow-up.

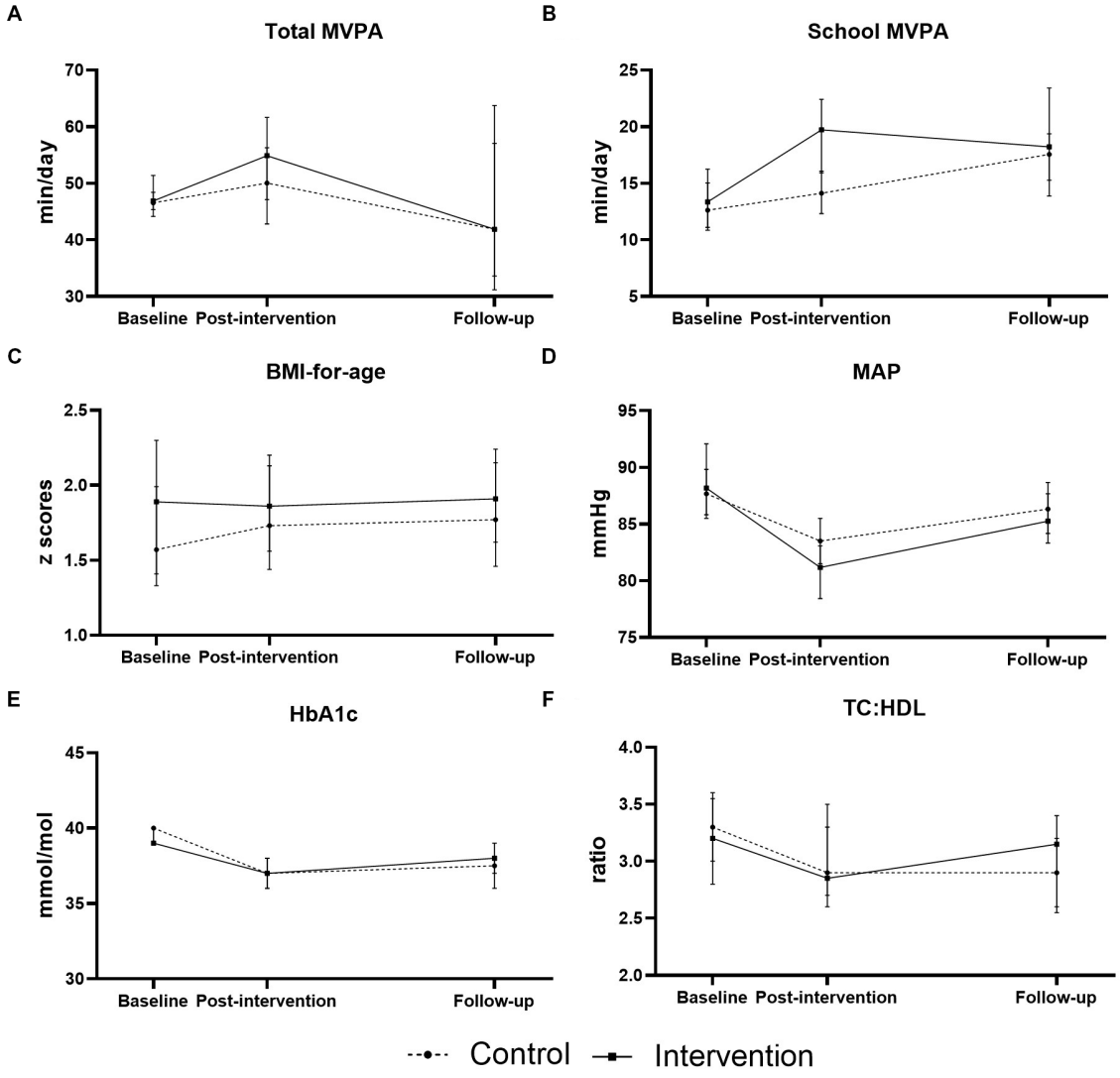

FIGURE 2
Longitudinal changes in cardiometabolic risk factors in children at risk of noncommunicable diseases. Changes from baseline to post-intervention and from post-intervention to follow-up are represented by intervention arm for **(A)** total moderate to vigorous intensity physical activity (total MVPA), **(B)** in-school moderate to vigorous intensity physical activity (school MVPA), **(C)** sex- and age-adjusted body-mass-index (BMI-for-age), **(D)** mean arterial pressure (MAP), **(E)** glycated haemoglobin (HbA1c), and **(F)** total cholesterol to high-density lipoprotein ratio (TC:HDL).

4. Discussion

The main findings of this study are that the *KaziKidz* school-based intervention had beneficial short-term effects that differed depending on the children's cardiometabolic risk profile, and that the observed effects lessened over time in vulnerable children. In the short-term, the intervention was effective in increasing during school MVPA for physically inactive children and among girls regardless of initial PA levels. At the same time, the intervention reduced MAP for all children, while only healthy children's HbA1c and TC to HDL ratio levels decreased significantly. At the 2 year follow-up, the intervention effects were not maintained in children at risk of NCDs, who showed lower total time spent in MVPA and elevated zBMI-for-age, MAP, HbA1c and TC to HDL ratio levels.

Our first aim was to study the immediate effect of a health-enhancing physical education intervention on cardiometabolic indicators in children at risk of NCDs compared to their healthy peers.

Although mixed results have been reported for school-based programs targeting PA, our findings are in line with those of a recent umbrella review (32). In this overview, Mannocci and colleagues found small increases in PA among children. However, the significant improvement in-school MVPA was not observed in total MVPA. Disagreement between in-school PA participation and total movement throughout the day has already been described. Favorable effects on PA levels during PE classes and school hours were not mirrored by a positive impact during leisure time (16), or were attenuated by inactivity after school (14). So far, the focus around the health benefits of PA has been on total MVPA across the day. We argue that neglecting interventions that prove effective in increasing MVPA

during the school time would be a missed opportunity to reach certain subgroups with less inherent motivation or opportunities to move outside of school hours.

In fact, the positive results found on school MVPA were on children with low initial levels of PA, as well as in girls independent of their activity status. These findings differ from that of a pooled analysis that detected a positive effect on PA for already active children, but not for inactive children or girls (33). Similarly, Love et al. did not find evidence of variable efficacy by sex (14). One possible explanation is that our intervention was better suited to meet the specific needs of inactive children and girls compared to the studies included in these analyses. Concretely, the *KaziKidz* toolkit aims to integrate movement into the learners daily lives through fun and games, rather than with competitive team games. The latest has been identified as a barrier of girls' participation in physical activities (34). Moreover, increasing movement levels in these groups could help develop their motoric skills and, ideally, create long-lasting positive attitudes towards PA. As high-intensity PA has been repeatedly associated with better cardiovascular outcomes (35), even small increases in PA levels accumulated over time could have meaningful clinical implications in at-risk populations.

Conflicting results exist about the potential of interventions to modify cardiometabolic risk markers. In our study, the intervention did not affect BMI levels in neither normal weight or overweight learners. However, it lowered MAP for children with and without pre-existing elevated BP. Furthermore, a significant improvement in glucose and lipid levels was only observed among children with no glycemic or lipidemic disorders, respectively. Poor cardiovascular health in children is oftentimes associated with unhealthy habits. Changing at-risk behaviors through lifestyle interventions has proven challenging. For example, limited results in BMI reduction among severely obese children and sustainability issues have been described (36). It is possible that longer intervention duration or higher intervention intensity might be needed to see an improvement, or that our intervention did not meet the specific needs of children with existing health disorders. Considering that high-risk subgroups are more susceptible to adverse health outcomes across the life-course, more research is imperative to identify effective and sustainable interventions in these groups.

The second aim of the study was to assess the long-term development of risk factors in especially vulnerable children. In general, the cardiometabolic risk profile of at-risk children worsened over time. However, results must be interpreted in the context of the COVID-19 pandemic, as South Africa employed one of the strictest lockdown measures globally. The 2 year follow-up assessments took place after children re-entered schools and while operating at 50% capacity.

A decline in total MVPA of over 11 min/day, although not statistically significant, was observed from October 2019 to October 2021. This reduction is higher than the 8 min/day reported for a population of school-aged English children between Summer 2018 and Autumn 2021 in the United Kingdom, which would be broadly equivalent to the expected natural decline observed with age (37). Consequently, we saw an increase of almost 10% in the prevalence of physical inactivity compared to baseline. Interestingly, the median school MVPA increased. We speculate that families maintained limited physical and social contact after COVID-19-related restrictions were lifted, limiting children's playtime outdoors. Meanwhile, schools would present as an alternative space for free and safe movement, and play. Our results point towards a longstanding adverse effect of the COVID-19 pandemic on PA levels, and potentially other cardiometabolic risk factors.

Indeed, a deterioration of children's health during the COVID-19 pandemic has been reported by other authors, although evidence is limited and heterogeneous. In our study we found a significant increase in MAP at follow-up, and small, non-significant changes in HbA1c and TC to HDL ratio. Our observations are in line with one study that found significant changes in HbA1c and lipid levels among dyslipidemic children (38). Another study in children with type 1 diabetes found a generalized decline in cardiometabolic risk factors including lipid parameters (39). Furthermore, an increase in pediatric type 2 diabetes during the COVID-19 pandemic has been reported (40). The higher consumption of salty and sweet foods and beverages noted during lockdown periods (41), may be one cause of health decline. Moreover, because PA is inversely associated with cardiometabolic risk factors (42), it is reasonable to think that the decline in total MVPA might partly explain the raise in BP, glucose and lipid levels observed in our study population. Notably, we did not see a significant increase in zBMI-for-age among overweight children post-pandemic. Our observation aligns with that of Weaver and colleagues, who found a significant acceleration in zBMI values in children with normal weight but not in overweight or obese children (43). Discrepancies between norm weight and overweight children have been corroborated by a meta-analysis (44). Arguably, these differences might stem from pre-pandemic behavioral patterns, with overweight children engaging in less health-supporting lifestyles that in turn, were not impacted by the pandemic. Because our study is intertwined with the COVID-19 pandemic, the extent to which the observed changes follow a secular trend or result from exposure to the epidemic remains unclear. Thus, future research should look into the long-term consequences of the COVID-19 pandemic both in healthy and vulnerable children.

Finally, we aimed to evaluate whether the effects observed in at-risk children post-intervention could be maintained over time. In line with previous research, we could not detect any outcome differences between the intervention and control groups at the 2 year follow-up (45). However, the scarcity of evidence on long-term intervention effectiveness makes it difficult to compare our results to others. As pointed out by one systematic review "more research is required with long-term follow-up to study the sustainability of (initial positive) changes" (46). Furthermore, the COVID-19 pandemic forced the closure of South African schools between March and June 2020. Upon reopening, social distancing protocols were put in place and the academic curriculum was trimmed to make up for the loss in schooling days (47). Consequently, it is likely that physical education has been neglected during this period. Thus, we cannot conclude whether the lack of long-term effect lies on the intervention itself, or rather its forced discontinuation due to the COVID-19 pandemic and the consequences thereof. These findings support the notion that systematic changes that integrate effective interventions into the structure of organizations are needed to ensure maintenance of positive effects. This is especially true in challenging settings like ours, where possibilities for PA are scarce.

4.1. Strengths and limitations

Strengths of this study include the use of a RCT with a longitudinal design, that allowed us to follow-up a vulnerable population including pre- and post-COVID-19 measurements. Furthermore, the availability of quality data, especially device-based PA, which is rare in relatively large sample sizes and low-income settings like ours. However, our study also had some limitations. First, intervention schools participated in different conditions with three of four schools receiving external support, while intervention fidelity was not assessed. Nevertheless, the application of mixed linear models enabled us to account for the variability between schools, classes, and intervention delivery. Second, low accelerometer wear-times might lead to inaccurate results. We approach this limitation by only including valid and representative days and controlling for wear-time in the analyses. Third, choosing appropriate cardiovascular risk markers and defining accurate cut-off points in children is a topic of debate in the literature. Different markers exist for different outcomes, and some change with age and maturation state of the child. Thus, using the same cut-off point for all children might present an under- or overestimation of the actual risk. This is partially overcome by the use of age- and sex-adjusted percentiles for BMI and BP, while none are available for glucose or lipids. Finally, as our study focuses on health outcomes of especially vulnerable children, no long-term data from healthy children was available to compare the development of cardiometabolic markers over time.

5. Conclusion

Our intervention was especially effective in improving high-intensity PA during school hours among less active children. It also improved cardiovascular risk factors, while benefit was higher for healthy children compared to at-risk children. Because we saw a deterioration in the long-term health outcomes of high-risk children, future studies should identify interventions that target the specific needs of vulnerable subgroups. Furthermore, intervention effects were lost in the long-term, possibly due to the program discontinuation during the COVID-19 pandemic. Moving forward, policymaking should provide for the integration of evidence-based interventions into resilient frameworks. This is of paramount importance if we aim to translate short-term benefits into long-lasting impact, especially for vulnerable populations living in challenging environments. In conclusion, schools are key settings to promote PA and improve health, but structural changes are necessary to ensure that effective interventions reach marginalized school populations and achieve sustainable impact.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Nelson Mandela University Human Ethics Committee (ref. no. H18-HEA-HMS-001 and H20-HEA-HMS-001), Eastern Cape Department of Education, Eastern Cape Department of Health Ethics Committee (EC_201804_00), and Northwest and Central Switzerland (ref. no. R-2018-00047 and Req-2020-00430). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin, while oral assent was sought from children.

Author contributions

PA, IM, RR, CW, UP, MG, HS, PS, JU, LA, JD, DD, NJ, MN, and SN designed the research and intervention. PA, IM, LA, JD, DD, NJ, MN, and SN conducted the research. PA conceptualized the study, analyzed and interpreted the data, and wrote the manuscript. HS supported with data analysis. All authors contributed to the article and approved the submitted version.

Funding

This research was financially supported by the Novartis Foundation (Basel, Switzerland) and the Swiss National Science Foundation (Bern, Switzerland; grant no. 192651), and took place under the auspices of the UNESCO Chair on "Physical Activity and Health in Educational Settings" (https://unesco-chair.dsbg.unibas.ch/en/). The funder had no role in study design, data collection, data analysis or data interpretation, nor the decision to submit the paper for publication.

Acknowledgments

The authors are grateful to the learners, parents/guardians, and educators for their participation in the study. We would like to thank Zaahira Ismail and Stefanie Gall for their assistance with data collection and data management. We would like to thank PD Christian Schindler, Swiss Tropical and Public Health Institute, for statistical support and advice.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1199381/full#supplementary-material

References

1. Stanaway JD, Afshin A, Gakidou E, Lim SS, Abate D, Abate KH, et al. Global, regional, and national comparative risk assessment of 84 Behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the global burden of disease study 2017. *Lancet*. (2018) 392:1923–94. doi: 10.1016/s0140-6736(18)32225-6

2. World Health Organization. *Health for the world's adolescents: a second chance in the second decade* WHO (2014). Available at: https://www.who.int/publications/i/item/WHO-FWC-MCA-14.05

3. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. *Lancet Child Adolesc Health*. (2020) 4:23–35. doi: 10.1016/s2352-4642(19)30323-2

4. World Health Organization (2021). *Obesity and overweight updated*. WHO. (Accessed on June 9, 2021). Available at: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

5. Song P, Zhang Y, Yu J, Zha M, Zhu Y, Rahimi K, et al. Global prevalence of hypertension in children: a systematic review and meta-analysis. *JAMA Pediatr*. (2019) 173:1154–63. doi: 10.1001/jamapediatrics.2019.3310

6. Watkins D, Hale J, Hutchinson B, Kataria I, Kontis V, Nugent R. Investing in non-communicable disease risk factor control among adolescents worldwide: a modelling study. *BMJ Glob Health*. (2019) 4:e001335. doi: 10.1136/bmjgh-2018-001335

7. World Health Organization. (2022). *Physical activity*. WHO. (Accessed on October 5, 2022). Available at: https://www.who.int/news-room/fact-sheets/detail/physical-activity

8. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *Int J Behav Nutr Phys Act*. (2010) 7:40. doi: 10.1186/1479-5868-7-40

9. Salvini M, Gall S, Müller I, Walter C, du Randt R, Steinmann P, et al. Physical activity and health-related quality of life among schoolchildren from disadvantaged Neighbourhoods in Port Elizabeth. *South Africa Qual Life Res*. (2018) 27:205–16. doi: 10.1007/s11136-017-1707-1

10. Gerber M, Müller I, Walter C, du Randt R, Adams L, Gall S, et al. Physical activity and dual disease burden among South African primary schoolchildren from disadvantaged neighbourhoods. *Prev Med*. (2018) 112:104–10. doi: 10.1016/j.ypmed.2018.04.001

11. World Health Organization. *Saving lives, spending less new WHO investment case for NCDs* WHO (2020). Available at: https://www.who.int/publications/i/item/WHO-NMH-NVI-18.8

12. Carson RL, Castelli DM, Beighle A, Erwin H. School-based physical activity promotion: a conceptual framework for research and practice. *Child Obes*. (2014) 10:100–6. doi: 10.1089/chi.2013.0134

13. Jones M, Defever E, Letsinger A, Steele J, Mackintosh KA. A mixed-studies systematic review and meta-analysis of school-based interventions to promote physical activity and/or reduce sedentary time in children. *J Sport Health Sci*. (2020) 9:3–17. doi: 10.1016/j.jshs.2019.06.009

14. Love R, Adams J, van Sluijs EMF. Are school-based physical activity interventions effective and equitable? A meta-analysis of cluster randomized controlled trials with accelerometer-assessed activity. *Obes Rev*. (2019) 20:859–70. doi: 10.1111/obr.12823

15. Pfledderer CD, Burns RD, Byun W, Carson RL, Welk GJ, Brusseau TA. School-based physical activity interventions in rural and urban/suburban communities: a systematic review and meta-analysis. *Obes Rev*. (2021) 22:e13265. doi: 10.1111/obr.13265

16. Errisuriz VL, Golaszewski NM, Born K, Bartholomew JB. Systematic review of physical education-based physical activity interventions among elementary school children. *J Prim Prev*. (2018) 39:303–27. doi: 10.1007/s10935-018-0507-x

17. Nguyen S, Hacker AL, Henderson M, Barnett T, Mathieu ME, Pagani L, et al. Physical activity programs with post-intervention follow-up in children: a comprehensive review according to categories of intervention. *Int J Environ Res Public Health*. (2016) 13:664. doi: 10.3390/ijerph13070664

18. Müller I, Schindler C, Adams L, Endes K, Gall S, Gerber M, et al. Effect of a multidimensional physical activity intervention on body mass index, skinfolds and fitness in South African children: results from a cluster-randomised controlled trial. *Int J Environ Res Public Health*. (2019) 16:232. doi: 10.3390/ijerph16020232

19. Uys M, Draper CE, Hendricks S, de Villiers A, Fourie J, Steyn NP, et al. Impact of a South African school-based intervention, healthkick, on fitness correlates. *Am J Health Behav*. (2016) 40:55–66. doi: 10.5993/AJHB.40.1.7

20. Adom T, De Villiers A, Puoane T, Kengne AP. School-based interventions targeting nutrition and physical activity, and body weight status of African children: a systematic review. *Nutrients*. (2019) 12:95. doi: 10.3390/nu12010095

21. Lambrinou CP, Androutsos O, Karaglani E, Cardon G, Huys N, Wikstrom K, et al. Effective strategies for childhood obesity prevention via school based, family involved interventions: a critical review for the development of the Feel4Diabetes-study school based component. *BMC Endocr Disord*. (2020) 20:52. doi: 10.1186/s12902-020-0526-5

22. Müller I, Smith D, Adams L, Aerts A, Damons BP, Degen J, et al. Effects of a school-based health intervention program in marginalized communities of Port Elizabeth, South Africa (the Kazibantu study): protocol for a randomized controlled trial. *JMIR Res Protoc*. (2019) 8:e14097. doi: 10.2196/14097

23. Arnaiz P, Adams L, Müller I, Gerber M, Walter C, du Randt R, et al. Sustainability of a school-based health intervention for prevention of non-communicable diseases in marginalised communities: protocol for a mixed-methods cohort study. *BMJ Open*. (2021) 11:e047296. doi: 10.1136/bmjopen-2020-047296

24. Troiano RP, Berrigan D, Dodd KW, Masse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. (2008) 40:181–8. doi: 10.1249/mss.0b013e31815a51b3

25. World Health Organization. *Growth reference data for 5–19 years: BMI-for-age: World Health Organization (2007)*, (2020). (Accessed on September 13, 2020). Available at: https://www.who.int/growthref/who2007_bmi_for_age/en/

26. Villa JK, Silva AR, Santos TS, Ribeiro AQ, Sant'Ana LF. Metabolic syndrome risk assessment in children: use of a single score. *Rev Paul Pediatr*. (2015) 33:187–93. doi: 10.1016/j.rpped.2014.11.001

27. Flynn JT, Kaelber DC, Baker-Smith CM, Blowey D, Carroll AE, Daniels SR, et al. Clinical practice guideline for screening and management of high blood pressure in children and adolescents. *Pediatrics*. (2017) 140:e20171904. doi: 10.1542/peds.2017-1904

28. Association AD. 2. Classification and diagnosis of diabetes: standards of medical care in diabetes-2020. *Diabetes Care*. (2020) 43:S14–31. doi: 10.2337/dc20-S002

29. Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents and National Heart, Lung, and Blood Institute. Expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: summary report. *Pediatrics*. (2011) 128:S213–56. doi: 10.1542/peds.2009-2107C

30. Gall S, Adams L, Joubert N, Ludyga S, Müller I, Nqweniso S, et al. Effect of a 20-week physical activity intervention on selective attention and academic performance in children living in disadvantaged neighborhoods: a cluster randomized control trial. *PLoS One*. (2018) 13:e0206908. doi: 10.1371/journal.pone.0206908

31. Cohen J. *Statistical power analysis for the behavioral sciences. 2nd* ed Lawrence Erlbaum (1988).

32. Mannocci A, D'Egidio V, Backhaus I, Federici A, Sinopoli A, Ramirez Varela A, et al. Are there effective interventions to increase physical activity in children and young people? An umbrella review. *Int J Environ Res Public Health*. (2020) 17:3528. doi: 10.3390/ijerph17103528

33. Hartwig TB, Sanders T, Vasconcellos D, Noetel M, Parker PD, Lubans DR, et al. School-based interventions modestly increase physical activity and cardiorespiratory fitness but are least effective for youth who need them most: an individual participant pooled analysis of 20 controlled trials. *Br J Sports Med*. (2021) 55:721–9. doi: 10.1136/bjsports-2020-102740

34. Bailey R, Wellard I, Dismore H. Girls' participation in physical activities and sports: benefits, patterns, influences and ways forward In: . *Technical Report*: World Health Organisation (2004)

35. Tarp J, Child A, White T, Westgate K, Bugge A, Grontved A, et al. Physical activity intensity, bout-duration, and cardiometabolic risk markers in children and adolescents. *Int J Obes*. (2018) 42:1639–50. doi: 10.1038/s41366-018-0152-8

36. de Ferranti SD, Steinberger J, Ameduri R, Baker A, Gooding H, Kelly AS, et al. Cardiovascular risk reduction in high-risk pediatric patients: a scientific statement from the American Heart Association. *Circulation*. (2019) 139:e603–34. doi: 10.1161/CIR.0000000000000618

37. Salway R, Foster C, de Vocht F, Tibbitts B, Emm-Collison L, House D, et al. Accelerometer-measured physical activity and sedentary time among children and their parents in the UK before and after COVID-19 lockdowns: a natural experiment. *Int J Behav Nutr Phys Act*. (2022) 19:51. doi: 10.1186/s12966-022-01290-4

38. Schefelker J, Zhang X, Dodge A, Marten K, Dimailig G, Bartlett HL, et al. Impact of the COVID-19 pandemic on cardiometabolic health parameters in children with preexisting dyslipidemia. *J Clin Lipidol*. (2022) 16:643–8. doi: 10.1016/j.jacl.2022.06.006

39. Shah N, Khadilkar V, Oza C, Karguppikar M, Bhor S, Ladkat D, et al. Impact of decreased physical activity due to COVID restrictions on cardio-metabolic risk parameters in Indian children and youth with type 1 diabetes. *Diabetes Metab Syndr*. (2022) 16:102564. doi: 10.1016/j.dsx.2022.102564

40. Marks BE, Khilnani A, Meyers A, Estrada DE, Boughton J, Gai J, et al. 15-OR: the COVID-19 pandemic and new-onset pediatric type 2 diabetes. *Diabetes*. (2021):70. doi: 10.2337/db21-15-OR

41. Karatzi K, Poulia KA, Papakonstantinou E, Zampelas A. The impact of nutritional and lifestyle changes on body weight, body composition and cardiometabolic risk factors in children and adolescents during the pandemic of COVID-19: a systematic review. *Children*. (2021) 8:1130. doi: 10.3390/children8121130

42. Owen CG, Nightingale CM, Rudnicka AR, Sattar N, Cook DG, Ekelund U, et al. Physical activity, obesity and cardiometabolic risk factors in 9- to 10-year-old UK children of White European, South Asian and Black African-Caribbean origin: the child heart and health study in England (chase). *Diabetologia*. (2010) 53:1620–30. doi: 10.1007/s00125-010-1781-1

43. Weaver RG, Hunt ET, Armstrong B, Beets MW, Brazendale K, Turner-McGrievy G, et al. COVID-19 leads to accelerated increases in Children's BMI *Z*-score gain: an interrupted time-series study. *Am J Prev Med*. (2021) 61:e161–9. doi: 10.1016/j.amepre.2021.04.007

44. Chang TH, Chen YC, Chen WY, Chen CY, Hsu WY, Chou Y, et al. Weight gain associated with COVID-19 lockdown in children and adolescents: a systematic review and meta-analysis. *Nutrients*. (2021) 13:3668. doi: 10.3390/nu13103668

45. McEwan D, Rhodes RE, Beauchamp MR. What happens when the party is over?: sustaining physical activity behaviors after intervention cessation. *Behav Med*. (2020) 48:1–9. doi: 10.1080/08964289.2020.1750335

46. Singh A, Bassi S, Nazar GP, Saluja K, Park M, Kinra S, et al. Impact of school policies on non-communicable disease risk factors—a systematic review. *BMC Public Health*. (2017) 17:292. doi: 10.1186/s12889-017-4201-3

47. Ramrathan L. School curriculum in South Africa in the COVID-19 context: an opportunity for education for relevance. *Prospects*. (2021) 51:383–92. doi: 10.1007/s11125-020-09490-1

Chapter 7. Publication 5

Perceived acceptance and feasibility of the KaziKidz health promotion intervention among educators and caregivers in schools from South Africa

Patricia Arnaiz[1], Manfred Max Bergman[2], Harald Seelig[1], Larissa Adams[3], Danielle Dolley[3], Markus Gerber[1], Nandi Joubert[1,4,5], Siphesihle Nqweniso[3], Peter Steinmann[4,5], Jürg Utzinger[4,5], Rosa du Randt[3], Cheryl Walter[3], Uwe Pühse[1], Ivan Müller[1]

[1]Department of Sport, Exercise and Health, University of Basel, 4052 Basel, Switzerland.

[2]Department of Social Sciences, University of Basel, Basel, Switzerland

[3]Department of Human Movement Science, Nelson Mandela University, Gqeberha, South Africa

[4]Swiss Tropical and Public Health Institute, Allschwil, Switzerland

[5]University of Basel, Basel, Switzerland

Submitted to:

BMC Public Health on 2nd July 2023.

Under peer review since 12th August 2023.

Perceived acceptance and feasibility of the *KaziKidz* health promotion intervention among educators and caregivers in schools from South Africa: a qualitative descriptive study

Patricia Arnaiz[1*], Manfred Max Bergman[2], Harald Seelig[1], Larissa Adams[3], Danielle Dolley[3], Markus Gerber[1], Nandi Joubert[1,4,5], Siphesihle Nqweniso[3], Peter Steinmann[4,5], Jürg Utzinger[4,5], Rosa du Randt[3], Cheryl Walter[3], Uwe Pühse[1], Ivan Müller[1]

Author's affiliations

[1] Department of Sport, Exercise and Health, University of Basel, Basel, Switzerland

[2] Department of Social Sciences, University of Basel, Basel, Switzerland

[3] Department of Human Movement Science, Nelson Mandela University, Gqeberha, South Africa

[4] Swiss Tropical and Public Health Institute, Allschwil, Switzerland

[5] University of Basel, Basel, Switzerland

***Corresponding author**

Patricia Arnaiz

E-mail: patricia.arnaiz@unibas.ch

ABSTRACT

Background: Despite the uncontested benefits of physical activity, its promotion lags behind in the public health agenda of low- and middle-income countries (LMICs). School-based interventions are promising strategies to foster health during childhood, but evidence of their effectiveness is limited and inconclusive for LMICs. Thus, further investigation is needed on contextual factors associated with intervention implementation in low-resource settings. We studied the acceptability and feasibility of the *KaziKidz* health promotion intervention and its implementation and make recommendations to improve future adoption and sustainability.

Methods: *KaziKidz* was implemented in four primary schools from low-income communities in South Africa in 2019. Semi-structured interviews with four school principals, three focus group interviews with 16 educators, and another three with 16 caregivers were conducted between October and November 2021. Participants were purposively recruited. Interview transcripts were analyzed via thematic analysis using a deductive and reflexive approach.

Results: Three main themes influencing intervention implementation and adoption were identified: (1) prioritizing teachers' needs, (2) integrating the program into the school structure, and (3) creating opportunities in the community. Supporting recommendations included: (theme 1) adopting intervention approaches that are inclusive of educators' health and providing them with capacity development and external support; (theme 2) fostering a feeling of ownership and belonging among school stakeholders to adapt interventions to specific resources and needs; and (theme 3) raising awareness in the community for increased power.

Conclusions: Comprehensive interventions comprising health support and adequate training for educators combined with environmental actions and communication strategies that hold key stakeholders accountable for program ownership can enhance uptake of school-based interventions and long-term maintenance.

Trial registration: ISRCTN15648510, registered on 17/04/2020.

Keywords: School-based interventions, physical activity, health promotion, acceptability, feasibility, teacher, caregiver, South Africa.

INTRODUCTION

The benefits of physical activity (PA) for health and adequate development in childhood are widely recognised (1-3). Yet, physical inactivity is widespread among school-aged children. In Sub-Saharan Africa, the prevalence of insufficient PA among adolescents amounts to 86%, making it the second-highest globally (4). Despite physical inactivity being long identified as a global health issue and a pandemic in itself (5), the promotion of PA has received little attention, particularly in low- and middle-income countries (LMICs), where infectious disease prevention remains the primary focus of the public health agenda (6). As a result, little progress has been observed in promoting PA in LMICs (7). The Global Observatory for Physical Activity reports high inequalities among countries and regions in their capacity for promoting PA, with Africa having the lowest capacity (6). Therefore, there is a call to action to implement effective policies and programs to increase PA levels in the African population, especially in children (8).

School-based interventions are promising and cost-effective strategies to foster healthy, active lifestyles early in life (9). The multi-component *KaziKidz* program was developed based on the UNESCO criteria for Quality Physical Education to promote health and physical literacy

in under-resourced public primary schools in South Africa (SA) (10, 11). Positive intervention effects on cardiovascular parameters and PA levels have been observed for the *KaziKidz* program (12, 13) and similar comprehensive programs (14). Still, inconsistent results on the effectiveness of school-based health-enhancing interventions have been reported worldwide (15) and in Africa (16). A systematic review found differences between rural and urban settings (17), suggesting that the context influences program success. The discrepant results and limited evidence from LMICs (18) underscore the need to investigate contextual factors and specific challenges associated with program implementation in low-resourced schools.

Implementation research seeks to facilitate the uptake of evidence-based practices in real-life settings (19). It aims to ensure effective implementation and sustainment of interventions by identifying and addressing context-specific challenges that influence their delivery. To examine the conditions surrounding the implementation of interventions, Proctor and colleagues defined a series of implementation outcomes (20). Outcomes such as acceptability, i.e. perception among implementation stakeholders, and feasibility, i.e. the extent to which an intervention can be successfully implemented, are crucial to understanding implementation processes and recognizing areas of weakness.

Indeed, poor deployment can hinder the success of otherwise effective initiatives. The importance of assessing the implementation quality of school-based health interventions has been previously reported (21). Authors have claimed that strengthening implementation research on PA programs can provide context-specific information that supports schools in their effective implementation (22). While several studies have described facilitators and barriers of school-based PA interventions, evidence suggests that further research is necessary to develop strategies that put this evidence into action (23). Thus, a need exists to accelerate our understanding of successful implementation strategies and ensure that effective interventions are successfully established in diverse settings and populations.

Hence, the main purpose of this paper is to inform practitioners and policy makers on evidence-based implementation strategies to guide the future of *KaziKidz* and other health promotion interventions in schools. Specifically, we aimed to understand the acceptability of the *KaziKidz* intervention by exploring educators' and caregivers' perceptions thereof, and to analyze the feasibility of both the intervention and its delivery by learning about the schools' experiences with the program implementation. Finally, we identify points of action and make

specific recommendations to improve the adoption, sustainability, and ultimately effectiveness of school-based interventions.

METHODS

Study design

This qualitative descriptive study is part of a mixed-methods project evaluating two school-based interventions: *KaziKidz*, a health promotion program for learners, and *KaziHealth*, a workplace health intervention for educators (24). Both interventions were implemented in the context of a randomized controlled trial in eight participating schools, four intervention and four control, in 2019 (10). Thereafter, the follow-up evaluation study involved a series of quantitative and qualitative assessments in 2021, using a convergent design to collate and analyze these data separately and draw overall conclusions (25). This paper examines the qualitative outcomes of the *KaziKidz* intervention and presents them in a descriptive manner.

Intervention

In the South African school system, physical education (PE) forms part of the life skills/life orientation (LS/LO) subject. Generally, PE is taught by non-specialists and little time is dedicated to it, approximately one hour per week per grade (26). The *KaziKidz* program aims to support LS/LO educators in delivering quality and comprehensive physical and health education. Its multi-component approach includes context-adapted and ready-to-use teaching materials with PA and dancing exercises, as well as health, hygiene, and nutrition lessons for grades 1 to 7; teacher training in the form of workshops or direct support from trained coaches; and environmental changes, like the provision of basic PA equipment (balls, ropes…) and games painted in the playground (hopscotch, four-square…)(27).

KaziKidz is coupled with the *KaziHealth* workplace intervention, which seeks to promote healthy lifestyles among primary school educators. *KaziHealth* consists of an individualized health risk assessment followed by lifestyle coaching that aims to increase personal knowledge and motivation.

Study setting

The participating schools were located in peri-urban, low-income communities in the Nelson Mandela Bay Municipality of the Eastern Cape Province of SA. These communities are characterized by poverty, high unemployment rates, and crime. All eight schools represent

public primary quintile 3 schools on the national poverty scale (1 represent poorest and 5 the least poor schools) and are non-fee-paying schools.

Participants

Purposive sampling was employed to identify study participants in the schools that implemented *KaziKidz* in 2019. School principals from the four intervention schools were invited to take part in the interviews. Three of these schools were asked to recruit eight educators and eight caregivers each to reach a total sample of 48 participants for the focus group interviews (FGIs). The final study sample consisted of four school principals, two female and two male, 16 educators, 12 female and 4 male, and 16 caregivers, 14 female and 2 male.

Data collection

Four semi-structured interviews with school principals and six FGIs, three with educators and three with caregivers, were conducted between October and November 2021. Three different interview guides were developed to reflect the particular role of each group. All guides contained questions pertaining to the participants' perception of and experiences with the program and its implementation (Additional file 1). Furthermore, prompts and follow-up questions were employed to invite interviewees to elaborate on their responses and maintain a balanced participation during the FGIs. Interview guides were pilot tested, and questions adapted accordingly.

All interviews and FGIs were conducted in-person, at the schools, and in English by an independent researcher, who was familiar with the research setting and briefed on the study. The first author (PA) was present in all interviews acting as observer and note-taker. A Xhosa native speaker, who is part of the research team, was also present and assisted with translation whenever needed. All sessions were audio recorded and lasted an average of 24 min for interviews with school principals and an average of 60 and 43 min for FGIs with educators and caregivers, respectively.

Data analysis

The interviews were transcribed verbatim and analysed via thematic analysis following the six-phase model proposed by Braun et al. in an iterative and reflexive manner (28). The analysis was done by the first author (PA), a female researcher with a public health background, who approached the analysis in a primarily semantic and inductive manner. The six analysis steps included (i) familiarization with the data, which started by taking notes during the interviews and continued by transcribing and re-reading the transcriptions; (ii) initial open coding in

MAXQDA Plus 2022 (VERBI Software, Berlin, Germany), followed by a revision that led up to more latent and nuanced codes; (iii) theme development, which involved the arrangement of codes into preliminary themes informed by thematic frameworks from the literature; (iv) theme refinement and (v) naming entailed a detailed analysis of the data with the help of thematic maps to find meaning across the dataset and alignment with the research question, which led to new, crosscutting themes; and (vi) writing up the report by collecting, editing, and situating the analysis in context. Compliance with Braun et al.'s 15 criteria for good thematic analysis guarantees methodological quality and rigor of the analysis (Additional file 2) (29).

RESULTS

Data from school principals, educators, and caregivers were combined to present a contextualized and in-depth picture of the *KaziKidz* program implementation in four primary schools in SA. The qualitative analysis revealed three main thematic areas across the interviews and FGIs relating to the participants' perceptions of the program and experiences with its implementation.

Table 1 presents the three key themes and sub-themes revealed by the thematic analysis. The main themes were: prioritizing teachers' needs, integrating the program into the school structure, and creating opportunities in the community.

Table 1. Main themes and sub-themes arising from transcript analysis.

Main themes	Sub-themes
1. Prioritizing educators' needs	1.1. Health and lifestyle
	1.2. Workload and expertise
2. Integrating the program into the school structure	2.1. Stakeholders' role
	2.2. Curriculum configuration
	2.3. Availability of resources
3. Creating opportunities in the community	3.1. Child development
	3.2. Caregiver involvement

Theme 1: Prioritizing educators' needs

School personnel expressed seeing educators as pivotal figures in program implementation and hence, their buy-in necessary for program success. However, a number of issues related to their personal health and professional responsibilities that influenced their motivation and availability to engage with the program arose in their discourse.

1.1 Health and lifestyle

Despite the fact that no questions concerning educators' health state were included in the interview guide, several participants mentioned health conditions and associated them with unhealthy lifestyles, for example sedentary behavior:

> *"I have arthritis, I'm truly lazy, sometimes when I come to school I request an Uber going home because it's hard to walk." (program coordinator, female, school 3)*

In turn, unhealthy habits and unfavorable attitudes toward sport were reported to have a negative impact on how educators engaged with the program.

> *"After the [KaziHealth health assessment] I discovered that I'm unhealthy with certain areas. I tried to be conscious, but to bring it down to the kids is not that easy. So I do not encourage my learners, the fact is… activity to me is strenuous and I'd rather sleep than exercise." (Educator, female, school 1)*

Meanwhile, educators from one school described being physically active and interested in sports as a sign of predisposition to get involved with the program.

> *"Many of us here are physically busy, exercising and so, so we will definitely get on board with this thing." (Educator, male, school 1)*

Educators' mental health seemed to be an issue of concern too.

> *"As we come to work each day we have a lot of challenges…We need moments where our cup is filled again, talk about our mental health, because if we're not mentally healthy, our bodies are going to feel weaker." (School principal, female, school 3)*

1.2. Workload and expertise

A high workload and pressure from the Department of Education to finalize the school curriculum was consistently reported. According to school principals and educators, the multitude of duties that educators must undertake on a daily basis engenders a sense of stress and a dearth of available time.

"There's not really time for them [educators]… the pressure from the department to finish the curriculum and complete the FATs, the formal assessment tasks, puts lots of pressure on the teacher." (School principal, male, school 2)

The stated pressure and scarcity of time undermined educators' motivation to engage in non-academic and extracurricular activities.

"The problem is time… We don't have the time because we are pushed, we have our own academics and things that we need to finish." (Educator, male, school 1)

Moreover, educators' inadequate training in PE was raised in accordance with the program's potential to increase teaching competency, which was regarded as positive.

"Programs like this just enrich and give us more opportunities, more grounds to speak on." (Educator, male, school 1)

Therefore, the educators' disposition toward the program was positive and hinted at a willingness to overcome the cited barriers and engage with the program:

"Since it's something that is for fitness, for health... I think it's very important. Because sometimes we get tired of even reading things, just taking the forms that you have given us, we'll say 'nah nah, we have to read now again?' But for the things that are important, we can do it." (Educator, female, school 1)

Theme 2: Integrating the program into the school structure

Embedding the program into the school day-to-day operations was also widely recognized to be key for successful program implementation and maintenance. It seemed that having a clear structure would minimize the stated motivational and logistical barriers. Nonetheless, respondents reported that adopting the intervention required a systemic approach, whereby diverse aspects of the school environment needed to be considered.

2.1. Stakeholders' role

It was outlined that establishing a school-wide initiative requires an effective and joint effort from all stakeholders involved and not just from educators.

"You need the SGB [School Governing Body], Department of Education, teachers, kids, everyone to buy into this idea… because it's a wonderful initiative, but it has to have everybody's involvement to get this program running and to operate at the optimal level." (Educator, male, school 1)

On the one hand, school principals acknowledged their role as a motivating force in launching the program and stimulating enthusiasm among educators.

"The school has got to come together and look at this thing in depth… It's got to start here in the office with a plan, and I'm sure by doing that the teachers will get on board." (School principal, male, school 1)

On the other hand, educators articulated that their active participation was imperative not only for program implementation but also to instill motivation in children. The perception of themselves as role models created a sense of responsibility that fostered their engagement.

"If I was just standing there, just being there, the learners will definitely not be interested. So I must show interest for them to be interested." (Educator, female, school 2)

Further, other influential stakeholders were mentioned. Specifically, the Department of Education was alluded to in its capacity as a policymaker and its potential to support incorporation, establishment, and dissemination of the program.

"The Kazi project is a good thing, but you need to bring it more to the front, speak to the people that's there in charge." (Educator, male, school 1)

2.2. Curriculum configuration

A prevailing agreement was observed regarding the syllabus' pronounced focus on academic performance, which together with the cited tight schedule and low teaching proficiency and motivation, contributed to the neglect of PE.

"So there is a program out but with limited emphasis on physical education… Learners learn through play and being active, but they don't get that opportunities. It's more academics in the classroom." (Educator, male, school 1)

Caregivers reinforced the perceived superiority of academic subjects by asserting that the amount of time allotted to PA decreases as children mature and require greater concentration on academic pursuits.

"Ever since grade five, in the afternoon, from half past three to nine o'clock at night we will sit with homework. There's no time for after school curriculums… I had to cut him off because his school marks came down a lot, so he had to focus more on school." (Caregiver, male, school 1)

Nevertheless, principals, educators, and caregivers alike agreed on the importance of adopting a holistic approach to education. They affirmed that the program's worth resided in its potential to complement the existing syllabus with non-academic content.

"It took the curriculum to another level in terms of showing the children besides the book work. We do a lot of book work… Where Kazi came and it showed the children, 'enjoy what you're doing'." (Educator, female, school 2)

Finally, educators recognized that the *KaziKidz* program aligned well with the current curriculum, reinforcing existing topics and providing practical teaching resources and tools.

"It does fit in the school curriculum because… everything that is taught on the life skills is what they are doing in Kazi, so that it helps them even more on that [teaching LS/LO]." (Educator, female, school 3)

2.3. Availability of resources

Several respondents mentioned that the schools' poor infrastructure and inadequate sports equipment were hindering factors for the practice and teaching of PE.

"Tools can also motivate the teachers to be able to take the children for physical education, but we don't really do it properly because of the lack [of equipment]." (School principal, female, school 4)

The resources offered with the program, namely, simple PA equipment, painted games, and posters, were consistently reported to assist teaching.

"Because they [educators] were also given certain tools and materials, which the school did not have… the teachers were able to take the children to the court… So I think that part also assisted a lot the educators." (School principal, female, school 4)

The materials provided also encouraged movement among learners.

"Those things [skipping ropes] even they [younger children] use it, they enjoy those types of things… the poorer schools that we are in don't have those resources" (Educator, female, school 2).

Resources other than infrastructure were mentioned by principals and educators. Concretely, staff shortage and teacher turnover indicated a negative impact on program maintenance.

"Another principal told me that three people [are] sick. The principal is also out of school more than a year now… And there is no money to pay substitutes." (School principal, male, school 2)

"Mrs [name] used to run the program, and then… she passed away, so she was the one that had control over all the facets of the program." (Educator, male, school 1)

Theme 3: Creating opportunities in the community

The perceived value of the program for children and its potential to have a positive impact on the wider community was identified as a significant factor contributing to its acceptability. This was especially true in connection with the unfavorable circumstances that characterize the study setting, such as poverty, unemployment, or crime, and hence, the opportunities that providing a holistic, quality education could bring.

3.1. Child development

Educators and caregivers noted that *KaziKidz* had a positive effect on children's wellbeing, behavior, and discipline.

> *"You can even see after the program the children got more self-confidence… They have a more positive mindset now." (Caregiver, female, school 2)*

Moreover, it was mentioned that lifestyle programs like the *KaziKidz* promoted tolerance and cooperation among peers, attitudes that are especially important in diverse communities.

> *"They learn team work. Most people come [to school] with different backgrounds, so they have to be tolerant of one another… So it is important that they get into those programs." (School principal, female, school 3)*

Participants also highlighted the significance of such programs for diversity and inclusion, as they provide opportunities for children who struggle with academic subjects and serve as motivators for attending school.

> *"They were quite excited to come to school. Some of the learners don't learn in class because of their own barriers. But when it comes to coming out and play, they enjoy that. So they come to school just for the sport and the physical education." (Educator, female, school 2)*

Overall, the program's potential to cultivate children's mindset, discipline, tolerance, and inclusion resulted in a sense of opportunity that is often absent in these communities.

> *"[The] KaziKidz program it's quite a good program for our school, taking into account the community that our learners are coming from, where unemployment rate is high, crime, poverty… We should be making sure that [each] child gets proper education and is equipped for the future." (School principal, female, school 3)*

3.2. Caregiver involvement

Accounts from principals and educators reflected a strong wish to involve children's guardians in the program, with the goal of adopting the knowledge and habits beyond the school setting and ultimately impacting the broader community.

> *"Who is the driving engine of the kids after school? It's the parents… They are stakeholders of it… because you are only stuck with the kids for certain amount of hours." (Educator, male, school 1)*

Caregivers themselves reported that information had gotten through to the home setting.

> *"Kids sometimes tell us… "don't eat too much food, don't eat too much meat'. When there are programs here in school, kids learn fast, then they come to us and they teach us." (Caregiver, female, school 3)*

However, their narrations demonstrated limited understanding. While some guardians mentioned not receiving any information, those who were aware of the program often confused it with the data assessment.

> *"I don't actually have a lot of information about this… Just my child was participating in it and she brought the thing [accelerometer] that she had to put on the stomach." (Caregiver, female, school 2)*

Moreover, respondents recognized that adopting healthy lifestyles is challenging given the adverse conditions of the communities they live in.

> *"There is a lot of unemployment in this community, so even to change your diet some of us can't afford it… Normally we do food that goes a long way." (Caregiver, female, school 2)*

In general, caregivers expressed a desire to be more informed about the program and to support their children.

> *"Bring the parents also to the table, so they can have a better understanding, we will know better how to answer all the questions [from children regarding the program]." (Caregiver, female, school 2)*

DISCUSSION

Participants provided insight into their perceptions and experiences for implementing the *KaziKidz* program in public primary schools. School principals and educators' narrations revealed that attending to educators' personal and professional needs is central to strengthening their engagement with the program. Furthermore, integrating the program into

the school system was recognized to facilitate delivery and maintenance. Finally, respondents acknowledged that adoption beyond the school setting is necessary to ultimately create a positive impact in the community.

The first theme identified in our study places educators in the spotlight of school-based interventions. We found that poor health and unhealthy lifestyles conditioned their attitude toward sport and ultimately hindered their engagement with the intervention. Notwithstanding the dependability on educators for implementing school-based programs, there has been a failure to acknowledge the influence of their health and wellbeing in adopting and sustaining said programs. While efforts to improve teachers' health exist, these have been done in isolation as opposed to being part of dual-approach programs tackling learners and educators' health simultaneously (30). The encountered conditioned narrative around educators' health is in line with a study from a similar context in SA (31), where the authors concluded that educators should be included as recipients of health-promoting programs carried out in schools. Yet, a review from 2021 shows that interventions targeting teachers' wellbeing are still scarce and more research is required (32). Furthermore, the suggested increased acceptability following educators' own intervention participation aligns with previous research showing that training concentrating on the wellbeing of teachers significantly increased their intention to implement school-based programs (33). Thus, in addition to the personal benefits for teachers themselves, attending to teachers' health and wellbeing can have a positive impact on the success of interventions. Nevertheless, other issues pertaining to the professional level were stated to have impacted their engagement with the program.

Our findings on barriers to implementing school-based PA programs are consistent with those frequently described in the literature, which include high workload, pressure to finalize the curriculum, and reduced time dedicated to non-academic subjects (34-36). The limited subject knowledge described in this study has also been reported as a hindering factor to delivering PE, together with the need for continued professional development (CPD) to increase subject competence and teaching confidence (37). Indeed, previous research has shown a good acceptance of teacher training designed to incorporate PA into the classroom as well as an improved teaching efficacy (35, 38). Strategies to increase PE teaching competencies become particularly relevant in the South African context, given the limited training that LS/LO teachers receive during their professional education. Stroebel and colleagues confirmed that

a major challenge for delivering PE in South African schools was the absence of qualified PE teachers. Hence, they advocate for collaboration between authorities and universities to offer adequate PE-specific in-service training for LS/LO teachers (39). Given the previously exposed barriers, it is imperative to establish schemes that provide support to teachers both in a personal and professional capacity.

The second theme discovered in our analysis shifts the focus from the educators to the school. The consensus that school accountability on academic performance pushes PE and extracurricular activities to the background was coupled with a positive view of the program's holistic educational approach. Indeed, the multi-component nature of the *KaziKidz* toolkit that integrates PA promotion, nutrition, and general education for healthier lifestyles has been described as a characteristic of successful intervention programs (40). Yet, it was emphasized that a supportive school environment is also needed to bring non-academic activities to the foreground. Whole-school approaches are long recognized as a requirement for "Health Promoting Schools" (41), whereby different strategies are put in place to promote health beyond curricular education. Moreover, the *KaziKidz* intervention builds on recommendations for school-based health promotion interventions in LMICs and reinforces individual behavioral change activities with improvements in the structural environment (42). One example is the provision of sports equipment. As reported by previous studies (43), we found that supplying PA materials was valued, facilitated implementation by overcoming a limitation of resources, and promoted motivation and movement among children. Nonetheless, many strategies to address environmental factors exist, and these must be adapted to the specific setting.

Because schools have different agendas, priorities, needs, and values, one-size-fits-all approaches to school-based health interventions might limit adoption. One study from the United Kingdom aimed to increase the autonomy of teachers and found that presenting them with a range of activities to choose from enhanced program adoption (44). However, the reception of increased self-determination might differ between high-income countries and LMICs. During the implementation of the HealthKick program in SA, the authors observed that teachers appreciated a structured way of preparing and teaching classes (45). Thus, a better approach to enhance program success in low-resourced schools in SA might be gathering stakeholders' input on how ready-to-use lessons can be implemented within the school schedule (42).

The last theme of this study concentrates on the importance of bringing new opportunities to deprived communities, especially for children. Caregivers and educators valued the potential of both PA and *KaziKidz* to positively influence children's physical and psychosocial health and wellbeing. Previous studies have suggested that school health programs can reduce health inequalities in socioeconomically disadvantaged communities, as PA interventions showed more beneficial results among children from low-income households (46). The program's capacity to impact the development and social skills of learners was also emphasized. Concretely, better behavior and discipline, as well as the possibility to promote the inclusion of intellectually challenged children were cited. These results align with one study that reported good acceptability and improvement in social-emotional skills of an intervention addressing fundamental motor skills and social and emotional development (47). However, for the reported benefits to be sustained over time and translated into long-term opportunities, learned behaviors need to be supported by the community.

Recommendations

Based on direct statements from the participants and identified underlying narratives, we have compiled strategies aiming at increasing the acceptability, feasibility, adoption, and maintenance of school-based health promotion interventions. Designing interventions that are inclusive of educators' wellbeing and providing them with capacity development could best address personal and professional barriers to program engagement. Furthermore, creating a sense of ownership among stakeholders could motivate the adaptation of the program to the schools' needs, thereby facilitating its integration. Similarly, involving learners and caregivers through increased awareness could inspire change in the community. Box 1 describes the recommendations per thematic area and we discuss them in the following paragraphs.

Box 1. Recommended strategies to increase uptake and maintenance of health promotion interventions in schools.

Recommendations based on theme 1: Prioritizing educators' health	
Intervention approach inclusive of educators' health	School-based interventions aiming to improve learners' health should adopt a comprehensive approach, whereby part of the program is specifically designed to attend to educators' health and wellbeing.

External support and capacity development	An appropriate introduction to the intervention through workshops and demonstration of activities should be ensured prior to implementation. In addition, strategies for capacity development, such as in-service training or CPD credits, should be offered in collaboration with higher education institutions.
Recommendations based on theme 2: Integrating the program into the school structure	
Feeling of ownership and belonging	Project partners should focus on transmitting a sense of ownership and belonging to the schools through close collaboration and adequate communication. To further reinforce program ownership by schools, a committee or champion responsible for the program and its implementation could be organized.
Program adaptation to resources and needs	To best embed interventions into schools and avoid delivery barriers, school stakeholders should first reflect on the characteristics of intervention and their available resources and needs. Then, both the intervention and its implementation should be adapted to fit the school requisites.
Recommendation based on theme 3: Creating opportunity in the community	
Awareness raising and empowerment	Future interventions should put in place effective communication strategies aimed at raising awareness in the community. A better understanding of the intervention values and goals could empower caregivers and learners to take ownership of the intervention and to adopt its message at home.

Theme 1: Prioritizing educators' needs

1. Intervention approach inclusive of educators' health

School principals and educators' stories were closely connected to their own participation in the *KaziHealth* teachers' health intervention, demonstrating a desire to position their experiences at the forefront of the conversation. In our experience, considering and addressing the individual needs of teachers substantially increased the acceptability of the *KaziKidz* intervention. Thus, we recommend school-based health programs to adopt a

comprehensive approach that broadens the program focus from a learner-centered to a school-community perspective, prioritizing the health and wellbeing of both learners and teachers. A recent systematic review of the mental health and wellbeing of school teachers has highlighted the relevance of co-designing health-promoting programs with teachers for teachers (48). To achieve this, it is crucial to include qualitative exploration of educators' lived experiences and desires, and to adopt a participatory approach to co-create inclusive interventions (49).

2. External support and capacity development

The type of support received from the research team was found to influence school principals' and educators' attitudes toward the intervention and experience with its delivery. Respondents from the schools that, besides the teaching materials, received either no external support or had two workshops, reported a limited understanding of the program. In contrast, the school that had additional support by a coach declared a more positive experience. Nevertheless, shortcomings regarding implementation facilitation were pointed out across all schools. Beyond good acceptability among teachers, it has been suggested that a supportive environment is critical to provide quality PE effectively (35). Thus, our recommendation to provide external support to kick-start the program together with continuous capacity development is in line with suggestions from Hill and colleagues, which seek to ensure that school-based health interventions are implemented as intended and sustained over time (45).

Theme 2: Integrating the program into the school structure

3. Feeling of ownership and belonging

Participants conveyed an interest in the successful implementation of the program, but frequently attributed the responsibility to external parties. A subset of educators from the unsupported school reported feeling detached from the program due to a perceived insufficient communication regarding their role and common goals. This indicates that close support from external parties can foster a feeling of belonging that motivates educators' active engagement. Moreover, it is equally important that schools take ownership of the program to ensure meaningful and sustainable implementation. The implied delegation of power suggests a need for greater emphasis on program ownership by schools. In line with earlier studies and participants' proposals, we advise for a person or group within the schools to be appointed responsible for program coordination (34).

4. Program adaptation to resources and needs

Our findings suggest that tailoring the intervention and its implementation to the unique characteristics of each school could assist with program delivery and fidelity, and ultimately improve effectiveness. For instance, one recurrent proposal was to allocate a specific time period within the school schedule for *KaziKidz*; however, suggestions on how to incorporate such periods varied between respondents. Therefore, initial collaboration with the schools is essential to ensure that the program addresses real needs and its implementation is feasible. Nevertheless, institutional support is still necessary for further adoption and maintenance. As stated by Lambrinou and colleagues "intervention programs delivered in vulnerable groups and/or low-socioeconomic areas should focus on school policy and environmental changes" (page 17) (50). Hence, policy frameworks that address curriculum prioritization are needed to facilitate structural changes that allow for health-promoting activities.

Theme 3: Creating opportunities in the community

5. Awareness raising and power claiming

Participants' accounts suggest that having a clear understanding of the program values and goals is essential not only for educators, but also to foster acceptance and adoption by learners and caregivers. Educators believed that effective communication could raise awareness among guardians and empower their engagement with the program. Indeed, previous research has shown that involving students actively and giving them greater autonomy to customize interventions creates a sense of accountability and program ownership (42, 44). Similarly, a systematic review found that activities that sought to engage caregivers directly, such as educational meetings, were more effective than indirect methods (51). These findings are in line with the educators' recommendations to involve caregivers in the program both to encourage pupil participation and to translate the results to the home context.

Limitations

The findings of this study provide valuable insights into the experiences of schools located in low socioeconomic communities in the Nelson Mandela Bay Municipality. However, given the subjectivity of the assessments made by particular participants and the sample size of this study, no inference can be made about the lived experiences of participants from other settings. While it can be hypothesized that limited training, curriculum pressures, and environmental challenges are shared realities in this population, further investigation across

different contexts is required to determine whether our findings are generalizable. A second limitation of this study is the lack of implementation monitoring. As a result, it is not possible to determine if some schools were more engaged with the program or if there were differences in the frequency or delivery mode between schools. This limitation highlights the need for further research into the relationship between intervention acceptability and delivery in multiple settings. Furthermore, despite following standard data collection and analysis procedures to remove bias, a remaining unconscious bias might still exist. For instance, participants may have provided inaccurate responses due to social desirability bias, recall bias, or others.

Conclusion

School-based interventions are important for children's development in low-income communities, but there are barriers that hinder their effective and continuous implementation. School principals and educators placed their lived experiences at the forefront of the narrative, highlighting the need for participatory approaches to understand the needs of program deliverers and co-design culturally appropriate interventions. The observed limited engagement from educators and caregivers emphasizes the relevance of effective communication strategies that convey the program's value to foster active involvement and context-specific adoption. A comprehensive approach to school-based interventions comprising health support, adequate training, and regular communication for educators coupled with school-wide actions and community awareness can hold key stakeholders accountable for program ownership, thereby increasing program uptake and long-term maintenance.

DECLARATIONS

Ethics approval and consent to participate

Ethical approvals for the overall trial including this qualitative study were obtained from the Nelson Mandela University Research Ethics Committee (ref. no. H20-HEA-HMS-001), the Ethics Committee Northwest and Central Switzerland (ref. no. Req-2020–00430) and the Eastern Cape Department of Education (07/12/2020). The trial has also been registered in the ISRCTN registry (ISRCTN15648510). In addition, all research methods were performed in accordance with the relevant guidelines and regulations as stated in the Declaration of

Helsinki. Prior to data collection, written informed consent was obtained from all the participants interviewed.

Consent for publication

Not applicable.

Availability of data and materials

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This research was financially supported by the Swiss National Science Foundation (Bern, Switzerland; grant no. 192651), and took place under the auspices of the UNESCO Chair on "*Physical Activity and Health in Educational Settings*" (https://unesco-chair.dsbg.unibas.ch/en/). The funder had no role in study design, data collection, data analysis or data interpretation, nor the decision to submit the paper for publication.

Authors' contributions

PA and MB conceptualized the qualitative study and prepared the interview guides. CW provided feedback to the guides. PA, LA, DD and SN recruited participants. PA analyzed and interpreted the study results. MB and HS provided supervision during data analysis. IM, UP, MG, and NJ provided feedback to the framework. PA wrote the first draft of the manuscript and all authors contributed to manuscript revision, read, and approved the submitted version.

Acknowledgments

The authors would like to thank the study participants who agreed to participate in the qualitative study and share their experiences. Furthermore, we are grateful for the contributions of the field team, specifically Ms Zaahira Ismail for the logistical support, Ms Alycia Boag for conducting the interviews, and Ms Sesethu Ncanywa, Ms Madeleine Nienaber, and Mr Alexander Elijah for assisting with the translation and transcription of the interviews.

REFERENCES

1. World Health Organization. Physical activity Geneva, Switzerland: World Health Organizationn.d. Available from: https://www.who.int/news-room/fact-sheets/detail/physical-activity. Accessed 09 May 2023.

2. Bidzan-Bluma I, Lipowska M. Physical Activity and Cognitive Functioning of Children: A Systematic Review. Int J Environ Res Public Health. 2018;15(4).
3. Poitras VJ, Gray CE, Borghese MM, Carson V, Chaput JP, Janssen I, et al. Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. Appl Physiol Nutr Metab. 2016;41(6 Suppl 3):S197-239.
4. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1·6 million participants. The Lancet Child & Adolescent Health. 2020;4(1):23-35.
5. Kohl HW, 3rd, Craig CL, Lambert EV, Inoue S, Alkandari JR, Leetongin G, et al. The pandemic of physical inactivity: global action for public health. Lancet. 2012;380(9838):294-305.
6. Ramirez Varela A, Hallal PC, Mejia Grueso J, Pedisic Z, Salvo D, Nguyen A, et al. Status and Trends of Physical Activity Surveillance, Policy, and Research in 164 Countries: Findings From the Global Observatory for Physical Activity-GoPA! 2015 and 2020 Surveys. J Phys Act Health. 2022:1-17.
7. Pratt M, Ramirez Varela AS, Deborah , Kohl III HW, Ding D. Attacking the pandemic of physical inactivity: what is holding us back? Br J Sports Med. 2020;54(13):759–62.
8. Douryang M, Tsafack Nanfosso KJ, Bouba Y. Physical Activity for Health Promotion and Disease Prevention in Africa and Cameroon: A Call to Action. J Phys Act Health. 2023:1-3.
9. Watkins D, Hale J, Hutchinson B, Kataria I, Kontis V, Nugent R. Investing in non-communicable disease risk factor control among adolescents worldwide: a modelling study. BMJ Glob Health. 2019;4(2):e001335.
10. Müller I, Smith D, Adams L, Aerts A, Damons BP, Degen J, et al. Effects of a School-Based Health Intervention Program in Marginalized Communities of Port Elizabeth, South Africa (the KaziBantu Study): Protocol for a Randomized Controlled Trial. JMIR Res Protoc. 2019b;8(7):e14097.
11. McLennan N, Thompson, Jannine. Quality Physical Education (QPE): guidelines for policy makers. Paris: United Nations Educational, Scientific and Cultural Organization; 2015.
12. Dolley D, du Randt R, Gerber M, Pühse U, Bosma J, Arnaiz P, et al. Effect of the KaziBantu school-based health intervention on non-communicable disease risk factors of children from low-income schools in Gqeberha, South Africa. African Journal for Physical Activity and Health Sciences. 2023a;29(4).
13. Arnaiz P, Seelig H, Gerber M, Adams L, Degen J, Dolley D, et al. Intervention effects and long-term changes in physical activity and cardiometabolic outcomes among children at risk of noncommunicable diseases in South Africa: a cluster-randomized controlled trial and follow-up analysis. Frontiers in Public Health. 2023;11.
14. Mannocci A, D'Egidio V, Backhaus I, Federici A, Sinopoli A, Ramirez Varela A, et al. Are There Effective Interventions to Increase Physical Activity in Children and Young People? An Umbrella Review. Int J Environ Res Public Health. 2020;17(10).
15. Neil-Sztramko SE, Caldwell H, Dobbins M. School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. Cochrane Database Syst Rev. 2021;9(9):CD007651.
16. Adom T, De Villiers A, Puoane T, Kengne AP. School-Based Interventions Targeting Nutrition and Physical Activity, and Body Weight Status of African Children: A Systematic Review. Nutrients. 2019;12(1).

17. Pfledderer CD, Burns RD, Byun W, Carson RL, Welk GJ, Brusseau TA. School-based physical activity interventions in rural and urban/suburban communities: A systematic review and meta-analysis. Obesity Reviews. 2021;n/a(n/a):e13265.
18. Barbosa Filho VC, Minatto G, Mota J, Silva KS, de Campos W, Lopes Ada S. Promoting physical activity for children and adolescents in low- and middle-income countries: An umbrella systematic review: A review on promoting physical activity in LMIC. Prev Med. 2016;88:115-26.
19. Peters D, Tran N, Adam T, Organization AfHPaSRWH. Implementation research in health: a practical guide. World Health Organization; 2013.
20. Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, Bunger A, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. Adm Policy Ment Health. 2011;38(2):65-76.
21. Duijster D, Monse B, Dimaisip-Nabuab J, Djuharnoko P, Heinrich-Weltzien R, Hobdell M, et al. 'Fit for school' - a school-based water, sanitation and hygiene programme to improve child health: Results from a longitudinal study in Cambodia, Indonesia and Lao PDR. BMC Public Health. 2017;17(1):302.
22. van Sluijs EMF, Ekelund U, Crochemore-Silva I, Guthold R, Ha A, Lubans D, et al. Physical activity behaviours in adolescence: current evidence and opportunities for intervention. The Lancet. 2021;398(10298):429-42.
23. Cassar S, Salmon J, Timperio A, Naylor PJ, van Nassau F, Contardo Ayala AM, et al. Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. Int J Behav Nutr Phys Act. 2019;16(1):120.
24. Arnaiz P, Adams L, Müller I, Gerber M, Walter C, du Randt R, et al. Sustainability of a school-based health intervention for prevention of non-communicable diseases in marginalised communities: protocol for a mixed-methods cohort study. BMJ Open. 2021;11(10):e047296.
25. Creswell JW, Plano Clark VL. Core Mixed Methods Designs. Designing and Conducting Mixed Methods Research. 3 ed: SAGE Publications, Inc; 2017. p. 50.
26. Stroebel LCE, Hay J, Bloemhoff HJ. Physical education in South Africa : have we come full circle? South African Journal for Research in Sport, Physical Education and Recreation. 2016;38(3).
27. KaziKidz - A school-based health intervention package enhancing children's overall health. Available from: https://www.kazibantu.org/kazikidz/. Accessed 02 July 2023.
28. Braun V, Clarke V, Weate P. Using thematic analysis in sport and exercise research. Routledge handbook of qualitative research in sport and exercise. London: Taylor & Francis (Routledge); 2016. p. 191-205.
29. Braun V, Clarke V. Using thematic analysis in psychology. Qualitative Research in Psychology. 2006;3(2):77-101.
30. Mini GK, Sarma PS, Thankappan KR. Cluster randomised controlled trial of behavioural intervention program: a study protocol for control of hypertension among teachers in schools in Kerala (CHATS-K), India. BMC Public Health. 2019;19(1):1718.
31. Draper CE, de Kock L, Grimsrud AT, Rudolph M, Nemutandani S, Kolbe-Alexander T, et al. Evaluation of a school-based physical activity intervention in Alexandra Township. South African Journal of Sports Medicine. 2010a;22(1):12-9.
32. Dreer B, Gouasé N. Interventions fostering well-being of schoolteachers: a review of research. Oxford Review of Education. 2021;48(5):587-605.

33. Cook CR, Miller FG, Fiat A, Renshaw T, Frye M, Joseph G, et al. Promoting Secondary Teachers' Well-Being and Intentions to Implement Evidence-Based Practices: Randomized Evaluation of the Achiever Resilience Curriculum. Psychology in the Schools. 2017;54(1):13-28.
34. van den Berg V, Salimi R, de Groot RHM, Jolles J, Chinapaw MJM, Singh AS. "It's a Battle... You Want to Do It, but How Will You Get It Done?": Teachers' and Principals' Perceptions of Implementing Additional Physical activity in School for Academic Performance. Int J Environ Res Public Health. 2017;14(10).
35. da Silva Bandeira A, Pizani J, de Sousa A, da Silva JA, Minatto G, Barbosa Filho VC, et al. Implementation of a school-based physical activity intervention for Brazilian adolescents: a mixed-methods evaluation. Health Promot Int. 2022;37(2).
36. Eyre ELJ, Adeyemi LJ, Cook K, Noon M, Tallis J, Duncan M. Barriers and Facilitators to Physical Activity and FMS in Children Living in Deprived Areas in the UK: Qualitative Study. Int J Environ Res Public Health. 2022;19(3).
37. Domville MS, Watson PM, Richardson DJ, Graves LEF. Educator perspectives on factors influencing children's school-based physical activity. Health Promot Int. 2019;34(5):931-40.
38. Gammon C, Morton K, Atkin A, Corder K, Daly-Smith A, Quarmby T, et al. Introducing physically active lessons in UK secondary schools: feasibility study and pilot cluster-randomised controlled trial. BMJ Open. 2019;9(5):e025080.
39. Stroebel LCE, Hay J, Bloemhoff HJ. Needs and challenges of foundation phase life skills teachers in delivering physical education: Jack of all trades and master of none? South African Journal for Research in Sport, Physical Education and Recreation. 2017;39(3).
40. Santos F, Sousa H, Gouveia ER, Lopes H, Peralta M, Martins J, et al. School-Based Family-Oriented Health Interventions to Promote Physical Activity in Children and Adolescents: A Systematic Review. Am J Health Promot. 2023;37(2):243-62.
41. Langford R, Bonell CP, Jones HE, Pouliou T, Murphy SM, Waters E, et al. The WHO Health Promoting School framework for improving the health and well-being of students and their academic achievement. Cochrane Database Syst Rev. 2014(4):CD008958.
42. Skar M, Kirstein E, Kapur A. Lessons learnt from school-based health promotion projects in low- and middle-income countries. Child Care Health Dev. 2015;41(6):1114-23.
43. Wang H, Zhou Y, Blake H, Chattopadhyay K. School-Based Physical Activity Intervention: A Qualitative Process Evaluation of a Feasibility Trial in Yangzhou, China. Int J Environ Res Public Health. 2022;19(2).
44. Christian DL, Todd C, Rance J, Stratton G, Mackintosh KA, Rapport F, et al. Involving the headteacher in the development of school-based health interventions: A mixed-methods outcome and process evaluation using the RE-AIM framework. PLoS One. 2020;15(4):e0230745.
45. Hill J, Draper CE, Villiers AD, Fourie JM, Mohamed S, Parker W-a, et al. Promoting healthy lifestyle behaviour through the Life-Orientation curriculum: Teachers' perceptions of the HealthKick intervention. South African Journal of Education. 2015;35(1).
46. Vander Ploeg KA, Maximova K, McGavock J, Davis W, Veugelers P. Do school-based physical activity interventions increase or reduce inequalities in health? Social Science & Medicine. 2014;112:80-7.
47. James ME, Bedard C, Bremer E, Cairney J. The Acceptability and Feasibility of a Preschool Intervention Targeting Motor, Social, and Emotional Development. Front Pediatr. 2020;8:319.

48. Beames JR, Spanos S, Roberts A, McGillivray L, Li S, Newby JM, et al. Intervention Programs Targeting the Mental Health, Professional Burnout, and/or Wellbeing of School Teachers: Systematic Review and Meta-Analyses. Educ Psychol Rev. 2023;35(1):26.
49. Draper CE, Thwala N, Slemming W, Lye SJ, Norris SA. Development, Implementation, and Process Evaluation of Bukhali: An Intervention from Preconception to Early Childhood. Glob Implement Res Appl. 2023;3(1):31-43.
50. Lambrinou CP, Androutsos O, Karaglani E, Cardon G, Huys N, Wikstrom K, et al. Effective strategies for childhood obesity prevention via school based, family involved interventions: a critical review for the development of the Feel4Diabetes-study school based component. BMC Endocr Disord. 2020;20(Suppl 2):52.
51. Verjans-Janssen SRB, van de Kolk I, Van Kann DHH, Kremers SPJ, Gerards S. Effectiveness of school-based physical activity and nutrition interventions with direct parental involvement on children's BMI and energy balance-related behaviors - A systematic review. PLoS One. 2018;13(9):e0204560.

Chapter 8. Synthesis and discussion

With the overarching objective of conducting a comprehensive evaluation of the *KaziKidz* health promotion intervention during its sustainability phase, the next chapter presents and discusses in detail the results of this PhD thesis. To that end, a synopsis of the primary findings from the relevant publications is presented, aligning with the specific aims of this research project (section 2.2). Thereafter, the findings are interpreted by discussing the convergence of the individual studies' results. To conclude, the methodological strengths and limitations are highlighted, followed by an exploration of far-reaching implications, and culminating in a final conclusion.

8.1. Synthesis of main findings

8.1.1. Risk identification: hypertension and physical activity

To begin with, the first two publications shed light on the variations among different blood pressure and physical activity assessment methodologies and their association with cardiometabolic markers in children, with the aim of determining the more suitable means to identify cardiovascular risk in our study population of school-aged children from South Africa.

Publication 1 presents the prevalence and risk of elevated blood pressure in our study cohort, which comprised 897 children (M_{age} = 10.4 years, *SD* = 1.2). After measuring blood pressure with an automated oscillometric device, percentiles were calculated to categorise hypertension based on four different standards: three international normative data representative of the United States, Germany, and a global population, as well as a pseudo-normative reference derived from the own study population. Notable differences were encountered across the standards, with hypertension prevalence ranging from 11.4% when pseudo-normative data was applied to 28.8% based on German guidelines. The American reference demonstrated the highest risk prediction of hypertension stage 2 with increasing BMI (*OR* = 1.72, *95% CI* = 1.43 to 2.07, p<.001), while the lowest risk was observed for the pseudo-normative data (*OR* = 1.51, *95% CI* = 1.18 to 1.92). Additionally, both the American and global standards had significantly higher rates of isolated systolic over diastolic hypertension (24.2% over 14.7% and 23.6% over 10.6%, respectively), a phenomenon that was not observed with the German or own study references.

Regarding physical activity measurement and its relationship to cardiovascular risk, publication 2 compared self-reports obtained from the PAQ-C with physical activity levels measured using the ActiGraph wearable device in a study population of 586 children (Mdn_{age} = 10 years, *95% CI* = 10.0 to 11.0). A significant yet weak correlation between the two instruments was observed for PAQ-C scores and MVPA (ρ = 0.10, p = .015). Furthermore, diverse patterns emerged when examining their association with various cardiometabolic markers, including BMI, blood pressure, blood lipids, and blood glucose. While ActiGraph-measured MVPA showed an inverse association with BMI (β = -0.03, *95% CI* = -0.04 to -0.02, p<.001), sedentary behaviour associated positively with total cholesterol (β = 0.001, *95% CI* = 0.000 to 0.002, p = .018). Meanwhile, PAQ-C scores were negatively associated with systolic blood pressure (β = -1.56, *95% CI* = -2.93 to -2.00, p = .025).

8.1.2. Intervention outcomes: efficacy and effectiveness

Publication 4 is divided into two parts. Initially, the study investigated the short-term effects of the *KaziKidz* intervention on physical activity and cardiometabolic outcomes in a sample of 961 children participating in the *KaziBantu* RCT (Mdn_{age} = 10.8 years, *95% CI* = 10.71 to 10.92). Schools were allocated to either the intervention group (N = 4) or the control group (N = 4). Intervention effects were assessed in a total sample of 961 learners and separately for children with different cardiovascular risk profiles, i.e. with and without risk factors for NCDs. Subsequently, the sub-cohort of high-risk children was followed up to assess the long-term development of the intervention effects two years' post-intervention (N = 280). In the short-term analysis, the intervention led to a significant increase in physical activity levels, specifically MVPA during school hours among girls (not at-risk: β = 1.80, *95% CI* = -0.22 to 3.82, p = .035; at-risk: β = 2.03, *95% CI* = 0.58 to 3.42, p<.001). However, no significant effect was observed for total MVPA or BMI. In addition, the intervention significantly reduced mean arterial pressure for all children (not at-risk: β = -1.77, *95% CI* = -3.14 to -0.70, p = .004; at-risk: β = -2.16, *95% CI* = -4.20 to -0.06, p = .008), while positive effects on blood glucose and lipids were found only among healthy children (HbA1c: β = -0.26, *95% CI* = -0.52 to -0.01, p = .037; TC to HDL ratio: β = -0.11, *95% CI* = -0.18 to -0.05, p = .002). Two years after the intervention ended, the achieved effects had declined and the general cardiovascular profile of at-risk children worsened, although non-significant changes

were observed except for blood pressure, which exhibited a significant increase of medium size between post-intervention and follow-up (z = -5.18, p<.001, r = 0.42).

8.1.3. Implementation outcomes: acceptability and perceived feasibility

The findings of the nested qualitative study are reported in publication 5. At the two-year intervention assessment, school personnel and caregivers were recruited purposively from the RCT intervention schools. Semi-structured interviews were conducted with the four school principals, while focus group interviews were separately carried out with 16 teachers and 16 caregivers to gain insights on their lived experiences with the programme. As a result, three main themes were identified. Firstly, school staff highlighted the importance of addressing educators' personal and professional needs as a priority to foster their involvement in the programme. Secondly, incorporating the programme into the school structure was found to support programme delivery and sustainability. Thirdly, respondents emphasised the significance of extending the programme's reach beyond the school to generate a positive impact on the wider community. Based on the key themes identified, recommendations were proposed to improve the uptake, delivery, and maintenance of the intervention. These recommendations included adopting an approach that considers educators' health, providing them with continuous capacity development, fostering a sense of ownership among stakeholders, adapting the programme to each school's resources, and raising awareness in the community.

8.2. Discussion

8.2.1. Intervention efficacy and cardiovascular risk

This thesis has provided valuable insights into measuring, identifying, and comprehending the relationship between cardiovascular risk factors and physical activity among school-aged children in South Africa. It has further shed light on the effects of a comprehensive intervention aimed at promoting physical activity and enhancing health in schools from economically disadvantaged areas of the country. This research offers a better understanding of the complex interplay between physical activity, cardiovascular health, and the potential benefits of school-based interventions in low-income settings.

In-school accelerometer-measured MVPA

The findings presented in publication 4 demonstrate the efficacy of the *KaziKidz* intervention in increasing MVPA during school hours among children whose initial levels of physical activity did not meet the recommendations. Interestingly, a noteworthy sex-dependent relationship emerged, wherein the intervention's positive effect on school MVPA was observed exclusively among girls regardless of their baseline activity levels, while no significant impact was observed among boys. This sex-specific response to school-based interventions contrasts with the current literature, which generally does not indicate differential effects on physical activity levels contingent upon sex or gender (Love et al., 2019; Schulze et al., 2020). Nevertheless, evidence is limited and some authors have reported greater benefits among girls (van Sluijs et al., 2021), while others have described an opposed, positive pattern for boys (Hartwig et al., 2021; Neil-Sztramko et al., 2021). A systematic review investigating the impact of mixed-sex school-based intervention on adolescent girls' physical activity found a very small positive effect, attributed to the influence of complex social and cultural norms (Owen et al., 2017). Consequently, it has been acknowledged that pathways to increase physical activity are likely to differ between boys and girls (Telford et al., 2016).

Notably, the sharp decline in physical activity during adolescence coincides with the peak of interaction of gender ideology with social influences (Bailey R, 2004). During this critical period, when children are exposed to gender norms around activities deemed suitable for boys versus girls, failing to adapt the types of sports offered in schools can erode enjoyment and body confidence, ultimately shaping attitudes and behaviours towards physical activity. Research has shown that girls often perceive lower sporting ability and a reduced enjoyment in physical activity and physical education than boys, resulting from traditional gender stereotypes and practices (Cairney et al., 2012; Cárcamo et al., 2020; Sport England, 2019). A narrow physical education curriculum with limited flexibility to cater to gender differences and dominated by competitive sports games has been identified as a discouraging factor for girls' participation (Bailey R, 2004; Owen et al., 2017). Conversely, adolescent girls seem to favour individual and creative activities, as exemplified by dance being a preferred activity among South African girls (Kinsman et al., 2015). Thus, *KaziKidz*'s holistic design and emphasis on games and enjoyment appears to offer an inclusive and culturally appropriate approach that addresses the specific needs of girls at school.

Still, girls' engagement in physical activity is influenced by numerous socio-ecological factors at the individual, community, and environment levels, with inadequate support from peers, family, and teachers being a prominent barrier (Duffey et al., 2021; Telford et al., 2016). This influence is especially prevalent in South Africa, where cultural ideals and community perceptions have been reported to deter healthy behaviours among women (Draper et al., 2016). Specifically, beliefs about body image, which start forming during adolescence, tend to encourage girls to conform to an ideal that promotes overweight rather than thinness, associating the latter to poverty and sickness (Kinsman et al., 2015; Puoane et al., 2010). In such contexts, schools become particularly relevant, necessitating measures to ensure equitable access to activities while creating an inclusive environment that reshapes gender norms around health and physical activity participation.

Accelerometer-measured MVPA and adiposity

The significance of both the *KaziKidz* intervention and the observed increase in MVPA must however be examined within the context of their public health implications for enhancing children's overall health.

Owing to the correlation between accelerometer-measured MVPA and BMI established in publication 2, a decrease in BMI might have been expected with rising levels of MVPA. In contrast, findings from publication 4 revealed no significant BMI changes as a result of the intervention. This discrepancy contrasts with the current body of evidence, which generally reflects modest but promising outcomes from school-based physical activity promotion initiatives in reducing BMI among children (Nally et al., 2021; Neil-Sztramko et al., 2021; Yuksel et al., 2020). Studies from South Africa have corroborated the positive influence of school-based physical activity promotion on body composition (Long et al., 2022; Müller et al., 2019a; Nqweniso et al., 2021a). Yet, conflicting results exist. A systematic review investigating the effectiveness of school-based programmes on weight modification in the African context revealed that around half of the interventions achieved significant effects, whereas most of the successful programmes specifically targeted overweight children (Adom et al., 2019).

Against this background, our results are further surprising considering that the intervention successfully raised MVPA levels among girls, a group that initially exhibited notably higher BMI levels, thus presenting a greater potential for change. However, the intervention did not seem to influence girls' BMI either (control: $MD = 0.16$; intervention: $MD = 0.21$). Sex has been identified

as a moderator in the efficacy of health-enhancing school interventions for reducing adiposity markers, with girls experiencing more pronounced benefits. For example, the *HEIA* study in Norway and the *KaziAfya* study in South Africa both documented improvements in body composition among girls, but not among boys (Grydeland et al., 2014; Long et al., 2022). Gerber et al. (2022) further confirm the importance of promoting physical activity in curbing overweight among South African girls, as lower MVPA increased the likelihood of adiposity, and girls faced an increased risk of being categorised as overweight and physically inactive.

It is possible however that potential changes in body composition might have been missed by the use of BMI as a surrogate measure of adiposity. Notwithstanding its endorsement by the WHO, research indicates that BMI lack suitability to detect body fatness due to its incapability to discern between weight variations from fat, lean muscle, or bone mass, specifically in childhood, contexts of weight loss with and without physical training, and among racial groups (Javed et al., 2014; Prentice & Jebb, 2001). Noteworthy are two interventional studies conducted in South Africa, which documented enhancements in body fat percentage, fat mass, and truncal fat mass but observed no significant changes in BMI (Monyeki et al., 2012; Nqweniso et al., 2021a). In contrast, in their systematic review, Yuksel et al. (2020) concluded that the impact of physical activity interventions on BMI was more pronounced compared to that on body fat percentage. It is worth highlighting that the absence of contributions from African studies to this observation underscores the possibility that distinct metrics possess varying capabilities to detect fluctuations in body fatness across settings.

Alternatively, the distinction between in-school and total MVPA may be considered to elucidate the absence of significant effects on BMI observed in this thesis. Importantly, the correlation between MVPA and BMI reported in publication 2 was established specifically for total MVPA. Interestingly, the achieved increase in MVPA levels among girls during school hours did not translate into extended MVPA engagement throughout the day. In other words, the intervention succeeded in fostering movement within the school environment, but did not prompt more active behaviours beyond school premises. The attenuation of positive effects at school when assessing overall activity across the day has been previously described, although contrary to our findings, these studies concurrently reported modest yet significant improvements in total MVPA (Jones et al., 2020; Kriemler et al., 2010; Metcalf et al., 2012). Cross-sectional investigations have also

demonstrated that elevating school-time MVPA can enhance daily MVPA, highlighting the potential of the school setting to influence children's physical activity levels (Kristiansen et al., 2021; Long et al., 2013; Nigg, 2022).

Furthermore, the lack of impact on total MVPA implies that the observed surge in school-time MVPA fell short of significantly contributing to the recommended minimum of 60 minutes per day at such intensities. In the intervention arm, both girls and boys accumulated four more minutes of in-school MVPA after the intervention compared to baseline (from 15 and 21 minutes to 19 and 25 minutes, respectively). This change resulted in a 6% rise in school-time MVPA contribution to the 60-minutes recommendation and a total contribution of 31% for girls and 41% for boys. The post-intervention in-school MVPA levels in the *KaziKidz* study align with the findings of Walter (2011) for similarly disadvantaged South African schools, where MVPA in school accounted for 37% for girls and 46% for boys of the daily 60 minutes of MVPA.

In sub-Saharan Africa and South Africa, children from lower socioeconomic strata are more bound to informal activities of lower intensity, such as house chores, than children from higher-income families (Hanson et al., 2019; Muthuri et al., 2014; Zimu et al., 2020). This trend is particularly prominent among girls. Studies from Nigeria and South Africa have found that adolescent boys spent significantly more time in informal, leisure-time physical activities and sports, whereas girls' activity tended to be of lower intensity and predominantly within the school and home settings (Hanson et al., 2019; Oyeyemi et al., 2016). As a result, girls from low-income communities heavily rely on their time at school to fulfil the recommended activity levels for their age. Thus, given that duration of MVPA has a stronger inverse relationship with adiposity among girls than boys (Miatke et al., 2021), longer time devoted to activities of moderate-to-vigorous intensity at school might be necessary to achieve noteworthy daily activity changes that in turn lead to relevant reductions in adiposity levels.

Self-reported physical activity and blood pressure

Nevertheless, publication 4 revealed beneficial effects on other cardiometabolic parameters. Concretely, the *KaziKidz* programme resulted in improved mean arterial pressure in children, irrespective of their initial hypertension risk status. Analogous to previous studies (Garcia-Hermoso et al., 2020), mean arterial pressure, serving as a comprehensive indicator of both systolic and diastolic blood pressure, was preferred for its higher validity over systolic blood pressure in

representing cardiometabolic risk in children (Martinez-Vizcaino et al., 2010; Villa et al., 2015). Nonetheless, a more detailed examination of systolic and diastolic blood pressure independently revealed a positive intervention impact on the former, both for children not at-risk (β = -4.21, *95% CI* = -6.00 to -2.57, p<0.001) and at-risk (β = -6.21, *95% CI* = -8.67 to -3.13, p<0.001), while no such effect was evident for the latter (not at-risk: β = -0.64, *95% CI* = -2.11 to 0.58, p=0.333; at-risk: β = -0.08, *95% CI* = -2.22 to 2.08, p=0.915).

In line with the observed programme outcomes, publication 2 identified a significant inverse relationship between self-reported physical activity and systolic blood pressure, but not diastolic blood pressure. Furthermore, a significant correlation was observed between PAQ-C scores and accelerometer-measured MVPA, with no association identified to light physical activity or sedentary time. This distinct correlation pattern aligns with earlier research (Marasso et al., 2021) and could be interpreted as the questionnaire's ability to reflect higher-intensity activities as opposed to overall physical activity levels. Indeed, the PAQ-C concentrates on rather organised activities, namely sports, dance, and play games, which tend to be more memorable for children and hence more accurately reported than sporadic bouts of activity characteristic of their age (Biddle et al., 2011). Conversely, the accelerometer's capabilities extend to capturing prolonged high-intensity activities as well as the shorter bursts of energy, smoothing the impact of longer, structured activities on the total activity volume (Aibar et al., 2014). It is therefore possible that the intervention might have increased the time dedicated to games and sports, activities that could have been better captured by PAQ-C, further explaining the effect seen on MVPA during school hours but not on total MVPA. In light of the extensive body of evidence supporting the benefits of physical activity on blood pressure in young individuals (Bull et al., 2020; Wellman et al., 2020), it is reasonable to infer that the enhanced activity levels in turn contributed to the decrease in children's mean arterial and systolic pressure.

Building on this supposition, it is also conceivable that these activities were, to some extent, of lighter intensity. Yet, it is worth considering that children, especially those with lower physical fitness, might have subjectively perceived these activities as strenuous, even if the defined accelerometer cut points for MVPA did not categorise them as such. Despite studies showing a dose-response relationship between physical activity and health benefits (Sriram et al., 2021), Weres et al. (2022) demonstrated that lighter forms of activity also protect against hypertension in

children. Additionally, a recent analysis involving 8,002 children and adolescents established that augmenting physical activity among children with initial lower aerobic fitness and as assessed via the PAQ, conferred greater advantages compared to their more fit counterparts (Nevill et al., 2020). The reduced physical fitness (Smith et al., 2020) and its association with clustered cardiovascular risk (Müller et al., 2020; Nqweniso et al., 2020) and hypertension (Joubert et al., 2021) has been documented in a population akin to that engaged in the *KaziKidz* programme. Thus, the premise here is that the intervention's potential to elevate activity levels, even at lower intensities and particularly among children with limited fitness, could have triggered a favourable response conducive to the reduction of blood pressure.

Sedentary behaviour and cholesterol

Furthermore, the intervention impacted the TC to HDL ratio levels of children, which might be explained by the significant association of accelerometer-measured sedentary behaviour with total cholesterol noted in publication 2. Previous cross-sectional and longitudinal studies in children and adolescents have outlined the link between sedentariness and elevated serum cholesterol independent of physical activity (Tremblay et al., 2011; Väistö et al., 2014). It is hence plausible that *KaziKidz* led to a decrease in sedentary time, which resulted in improved cholesterol levels among children without dyslipidaemia. Although possible, the veracity of this hypothesis remains uncertain, owing to the inconclusive evidence on the efficacy of school-based health-promoting interventions in curtailing sedentary behaviours (Hegarty et al., 2016; Jones et al., 2020; Nally et al., 2021; Santos et al., 2023; Yuksel et al., 2020).

Simultaneously, the well-established association of sedentary behaviours with adiposity and clustered cardiovascular risk in children globally and in South Africa might explain the lessened decline in TC to HDL ratio among children in the intervention group with increased baseline risk (Bull et al., 2020; Gerber et al., 2022; Joubert et al., 2021; Tremblay et al., 2011). It can be posited that children with initially compromised cardiovascular profiles might have been inclined towards more sedentary lifestyles, and that this behaviour proved challenging to change through the intervention. This assumption gains support from the fact that girls in the study exhibited significantly higher levels of both TC to HDL ratio and sedentary time compared to boys. Aligning with the aforementioned attenuation of physical activity throughout the day and echoing the concept of "compensatory behaviour" introduced by Jones et al. (2020), girls might have offset

increased activity during school hours with additional sitting time beyond school. This could clarify why initially elevated cholesterol levels persisted compared to healthier peers.

Nutrition and glycaemia

Besides the hitherto emphasis on physical activity, a point of interest of the *KaziKidz* intervention pertains to its holistic approach encompassing nutrition, hygiene, and overall health education in addition to movement and physical literacy. This integrative design implies that the observed betterment in cardiometabolic parameters may stem from factors beyond mere changes in physical activity. Hence, an increased health awareness and behavioural shifts, particularly improvements in dietary habits, could have contributed to the positive intervention outcomes reported in publication 4.

Notably, publication 2 did not establish a substantial correlation between blood glucose and physical activity domains, aligning with the conclusions of Nqweniso et al. (2021b) for a similar South African child cohort. Therefore, the potential influence of an enriched nutrition regimen, specifically the reduction of excessive dietary sugar intake and its associated risk for diabetes (Huang et al., 2023; Ooi et al., 2022), emerges as a plausible explanation for the noted improvement in HbA1c levels. Remarkably, South African youth exhibit alarmingly high dietary sugar consumption levels (Della Corte et al., 2021; Shisana et al., 2013), well surpassing the recommended limit of 10% of daily energy intake for children and adolescents (World Health Organization, 2015). Consequently, the intervention's potential to instil dietary improvements and reduce blood glucose among children with normative levels at baseline assumes importance. Nonetheless, akin to sedentary behaviours, the implementation of such lifestyle adjustments by high-risk children could have faced challenges, resulting in no apparent amelioration of their elevated plasma sugar levels.

Unfortunately, evidence concerning the impact of health-promoting and nutrition-related interventions on metabolic markers is scarce. Particularly in sub-Saharan Africa, research in this realm has primarily focused on anthropometric outcomes and micronutrient deficiencies as a strategy to tackle the coexistence of under- and over-nutrition in the region (Gerber et al., 2020; Kyere et al., 2020; Mbogori et al., 2020). Moreover, deciphering the specific impact of individual components within comprehensive interventions like *KaziKidz* poses complexity. As a result, the

causes leading to a decreased blood glucose in our study population remain speculative and warrant further exploration.

Definition of cardiovascular risk

Nevertheless, in the assessment of an intervention's efficacy, the attained changes in the desired outcomes must be considered in light of their clinical significance. In turn, establishing clinical significance is contingent on both the availability of a concrete, evidence-based definition and the reliable measurement of the outcomes of interest. However, the introduction has unveiled the existence of numerous definitions for single risk factors of NCDs in childhood. Moreover, increased risk is determined by specific thresholds, which not only vary for individual parameters but are often extrapolated from adult risk and particular population groups, introducing uncertainty to their applicability in diverse paediatric contexts. For instance, the American Diabetes Association (2020) widely accepted diagnostic criteria for diabetes have their origins in epidemiological studies in adults. Meanwhile, the relevance of these definitions in children remains ambiguous (Arslanian et al., 2018). Furthermore, these diabetes guidelines acknowledge disparities in HbA1c levels among racial and ethnic groups, casting doubt on the appropriateness of universal cut points across cultural contexts. Similar debates span other risk factors. For example, and supporting the above presented hypothesis regarding adiposity metrics, Agbo et al. (2020) have recently emphasised the limited utility of BMI in assessing abdominal obesity in sub-Saharan Africa, proposing abdominal height as a more adept indicator of cardiometabolic risk among adults. Therefore, the intricacy of defining real risk in children and across settings becomes more challenging due to the diversity of available assessment methods and the lack of standardisation in their application.

This complexity is epitomised in publication 1 and 2, which explored blood pressure and physical activity in South African children, exposing divergent results when different tools and thresholds were employed. Specifically, publication 1 highlights challenges associated with identifying hypertension in this population and advocates for the development of accurate, representative, regional standards. This call to action is mirrored in a critical review by Reisinger et al. (2021) discussing the discrepancies and clinical relevance of different metabolic syndrome definitions in children – a concept that represents the clustering of cardiometabolic risk factors. To mitigate misrepresentation of cardiovascular risk, the authors recommend definitions that are tailored to

race and ethnicity or geographical regions. Along these lines, Kruger et al. (2023) and Minja et al. (2022) explored the gaps and priorities pertaining to cardiovascular disease in Africa, underscoring the need for further research to develop region-specific nomograms and thresholds and so, to improve the accuracy of disease burden data and guide interventions in the region. Hence, this thesis argues that without robust measurements of risk factors for NCDs in the target populations, informed decisions on their optimal levels required for curbing cardiovascular risk remain elusive. Until then, the evaluation of the real impact of health promotion interventions and their optimisation to improve population health will be constrained.

8.2.2. Acceptability, perceived feasibility, and intervention efficacy

The impact of any public health intervention is not solely determined by its efficacy, as explored in publication 4, but also by its uptake, delivery, and integration within the specific targeted setting (Glasgow, 1999). Given that these complex interventions are deployed in real-world scenarios, complementary assessments are needed to better understand the implementation process (Proctor et al., 2011). It is important to recognise that limited intervention results may not arise from its inherent ineffectiveness, that is intervention failure, but rather from its poor application, referred to as implementation failure (Naylor et al., 2015; Proctor et al., 2011). This perspective is underscored by emerging research indicating that an inadequate execution of evidence-based school programmes is common across settings and a major barrier to their overall success (McKay et al., 2019; Moir, 2018). Nevertheless, a recent systematic review indicated that even with optimised implementation processes and intervention fidelity, school-based interventions still yielded small and varied effects on health outcomes (Wolfenden et al., 2022). Hence, it is imperative to examine the intervention's efficacy in the context of its real-world implementation to enable the differentiation and optimisation of both the intervention itself and its implementation.

<u>Lived experiences with implementation strategies</u>

By delving into the acceptability and perceived feasibility of the *KaziKidz* programme among school stakeholders, this thesis has gained a deeper understanding of the contextual factors that influence its adoption, implementation, and ultimately efficacy in under-resourced primary schools in South Africa, as elucidated in publication 5.

Notably, the narratives of teachers were strongly shaped by their own lived experiences, underscoring the consideration of their individual needs. Besides the overarching challenges pertaining to the South African educational system, schools in historically disadvantaged communities grapple with additional hurdles stemming from their unique environment. Predominant difficulties faced by these schools include insufficient funds, inadequate facilities and equipment, overcrowded classrooms, discipline issues among learners, unsafe learning environments, teacher shortages, poor professional training, and high stress levels and demotivation among educators (Amnesty International, 2020; Motseke, 2005; Peltzer et al., 2009; Zulu et al., 2019). Although the presence of such barriers was corroborated in the context of this study, educators exhibited a readiness to overcome them in support of the *KaziKidz* programme, driven by the perceived value it held for children in these communities.

However, teachers' perceptions of the intervention varied depending on the specific implementation strategy their respective schools participated in, namely whether they received additional support and, if so, the nature thereof. Educators from the school who benefited from workshops and a physical education coach described a largely positive experience. In contrast, teachers who exclusively partook in workshops reported a limited involvement and stated the need for a facilitator's presence. Meanwhile, educators from the cohort that solely received the *KaziKidz* teaching material expressed a similar sense of disengagement attributed to a lack of ownership and insufficient interaction with the research team. These divergent experiences parallel prior findings concerning the professional development of teachers in LMICs. A study found that initial in-person training coupled with mentoring and subsequent follow-up visits were the most successful characteristics of in-service teacher training (Popova et al., 2022). In South Africa, educators participating in upskilling training have recounted a sentiment of being "workshopped" rather than acquiring ownership of their own teaching (Dixon et al., 2014). In alignment with the conclusions drawn in publication 5, Kahts-Kramer et al. (2022) contend that a collaborative approach to professional development holds the potential to assist South African generalist teachers in surmounting both individual and systemic obstacles to physical education delivery.

Impact on intervention implementation

Owing to the disparity in educators' narratives regarding their experiences with *KaziKidz*, it is probable that intervention implementation varied across schools in terms of dose and fidelity.

While speculative, schools with limited or no external assistance might have failed to deliver the intervention as intended, possibly leading to suboptimal attainment of desired health outcomes. Consequently, the overall intervention efficacy observed in publication 4 could be influenced by weaker outcomes in these schools, thereby attenuating the more substantial effects achieved in others.

In line with this notion, Dolley et al. (2023a) examined the four different implementation strategies of the *KaziKidz* intervention separately, and their findings are supportive of this proposition. Their study revealed that while the toolkit alone showed marginal to no improvements on children's risk factors for NCDs, supplementation with workshops or a dedicated coach had a positive impact on MVPA levels and cardiometabolic parameters, respectively. Interestingly, Dolley's research and our own demonstrated that the most favourable outcomes alongside enhanced acceptability and feasibility were associated with the school that received support from both the workshops and the coach. This observation aligns with the review by Wolfenden et al. (2022), which reported that the most common implementation strategies for school-based programmes encompassed educational materials, meetings, and outreach visits. However, when evaluating the individual efficacy of different implementation strategies of health promotion programmes in schools, Darlington et al. (2018) found that including staff training did not enable implementation.

In conclusion, it is reasonable to argue that if implementation strategies are optimised and uniformly applied, that is, if all schools receive external support in the form of collaborative workshops coupled with an initial mentorship from coaches, the *KaziKidz* intervention might result in even more favourable health outcomes among children.

Impact on intervention effects

Moreover, insights from educators and guardians of children substantiate the observed effects of increased physical activity time during school hours, but not throughout the week. On the one hand, caregivers confirmed the importance of academics over other pursuits in the home setting, while all respondents agreed that safety issues and inadequate infrastructure are major impediments to the practice of physical activity in the community, especially for girls. This echoes previous documentation that parental concerns about safety and focus on educational endeavours hinder the participation of South African adolescent girls in sports and physical activities during leisure time (Kinsman et al., 2015). Similarly, South Africa's Healthy Active Kids Report Card

2022 identified deficiencies in community and environmental support for physical activity, particularly in organised sports, highlighting an exacerbated risk for girls and children from low-income areas (Naidoo et al., 2022). On the other hand, children's guardians exhibited a generalised moderate awareness about the *KaziKidz* programme, which diminishes the likelihood of parental support for healthier behaviours outside of school. Consistent with earlier research (Wang et al., 2022), time constraints emerged as a barrier to parental engagement both with the programme and the children's extracurricular activities. Additionally, family responsibilities and cultural roles likely further influenced attitudes and priorities towards physical activity. For instance, Muthuri et al. (2016) described a different likelihood of South African children meeting physical activity recommendations depending on parental education. Still, caregivers showed an interest in becoming more involved with the programme and supporting children's participation. Whether this willingness translates into concrete action remains unclear, given the challenges inherent in ensuring parental involvement in school-based physical activity interventions (Naylor et al., 2015).

Despite caregivers' limited familiarity with and involvement in *KaziKidz*, instances of the programme's positive impact on children's health awareness were cited, although predominantly related to nutrition. The remarkable association of the intervention with nutrition supports the premise that *KaziKidz*'s holistic approach might have prompted improvements in children's diets and, ultimately, the cardiometabolic parameters established in publication 4. Nonetheless, the potential shifts in dietary habits are likely to be modest, given respondents' reports of the unaffordability of nutritious foods, a widespread issue in both LMICs and South Africa (Miller et al., 2016; Vermeulen et al., 2023). In the latter, a school-based intervention demonstrated improved parental awareness of healthy behaviours, encouraging healthier food choices in their children (Nyawose & Naidoo, 2016). In this context, the reduced consumption of sugary beverages and unhealthy snacks, potentially leading to decreases in blood sugar, cholesterol, and blood pressure levels becomes plausible.

The realities exposed through the accounts of participants serve to reinforce our affirmation that children in general and girls in particular lean on educational institutions to acquire and engage in healthy, active lifestyles. School-based interventions hence remain an effective approach to instil healthy habits from a young age, especially in resource-scarce communities. Still, optimisation of

their implementation and an active role of key stakeholders is imperative to maximise intervention effectiveness and propagate healthier behaviours beyond the school setting.

8.2.3. Intervention continuity and effectiveness

Akin to optimising the implementation process to maximise an interventions' efficacy, ensuring intervention continuity is essential for sustaining long-term outcomes, henceforth referred to as effectiveness. This thesis has gained valuable insights into the development of intervention effects over time in children enrolled in the *KaziKidz* programme, particularly those at increased risk for NCDs.

Impact of the COVID-19 pandemic

The continuity of *KaziKidz* at the schools, and consequently its assessment, were hindered by the outbreak of the COVID-19 pandemic in March 2020. South Africa's response to the pandemic involved a total of four months of school closures in 2020, followed by a phased return with schools operating at 50% capacity (Spaull & Van der Berg, 2020). The reopening introduced a modified curriculum and social distancing measures, restricting non-essential activities and those that entailed close contact, including physical education (Ramrathan, 2021). This exceptional circumstance persisted until the assessments conducted for this thesis in October 2021.

While the global impact of the COVID-19 pandemic has been profound, LMICs have been disproportionally affected (Mahler et al., 2022). For children in these settings, the disruption of schooling carried significant implications owing to the unequal access to remote learning and negative effects on school attendance (Zar et al., 2020). In South Africa, a higher percentage of young children did not return to school in 2020 compared to the previous year (Statistics South Africa, 2021), jeopardising their futures and, according to our previous observations, their ability to engage in physical activities and adopt health-promoting behaviours.

Research has indeed highlighted the detrimental consequences of the pandemic and lockdown measures on children's physical activity and health. Notably, Cena et al. (2021) reported excessive weight gain related to altered eating patterns, reduced physical activity levels, and increased sedentary behaviours worldwide. Abbas et al. (2023) described the adverse physical and mental health consequences of decreased physical activity, heightened screen time, and social isolation. These trends align with the unfavourable cardiovascular development noted in publication 4

among high-risk children, including lowered total MVPA and elevated mean arterial pressure, adiposity, blood glucose, and cholesterol. Nevertheless, these changes were generally of small effect size. Interestingly, a multi-country study indicated that the impact of the COVID-19 pandemic on physical activity and sedentary time was relatively less marked for children in LMICs compared to those in HICs (Okely et al., 2021).

The dearth of evidence from Africa hampers a comprehensive understanding of the pandemic's and containment measures' impact on physical activity and health of children in the region, especially those living in socioeconomically disadvantaged areas (Rossi et al., 2021; United Nations Children's Fund (UNICEF), 2021). However, the documented effects on South African children in these contexts primarily relate to issues such as malnutrition, psychological distress, or learning setbacks (Spaull & Van der Berg, 2020). Therefore, factors beyond the COVID-19 pandemic likely contributed to the observed decline in health markers in our study population.

Particularly, the observed trajectory of physical activity, anthropometric measures, and clinical outcomes is in line with established maturation trends in this age group. Blood pressure, for example, typically rises with age, reaching adult levels during adolescence (Azegami et al., 2021; Cassimos et al., 1977; "The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents," 2004). Similarly, transient physiological elevations in HbA1c (Kelsey et al., 2021) and total cholesterol (Hickman et al., 1998) accompany sexual maturation. Furthermore, BMI increases (Cleland et al., 2022; Matsumoto et al., 2021) as well as reduced physical activity levels (Marques et al., 2020) are also common during puberty.

Maintenance of *KaziKidz*

Publication 4 further revealed that participation in *KaziKidz* seemingly did not counteract the worsening of cardiovascular health indicators over time. This lack of attenuation can be attributed to both the interruption of the intervention due to school closures and the documented challenges in maintaining positive intervention effects long-term. Although less extensive than for efficacy studies, the body of evidence regarding the effectiveness of school-based interventions points to declining benefits over time (Meyer et al., 2014; Nguyen et al., 2016). It is noteworthy however that this decrease is consistently associated with programme discontinuation, which in turn derives from intervention completion and the cessation of external funding (Herlitz et al., 2020; Tarp et al., 2018).

Along these lines, the sustainability of *KaziKidz* in the participating schools under normal circumstances remains uncertain. In their systematic review, Herlitz et al. (2020) concluded that upskilling and retaining motivated school leaders and staff is pivotal for maintaining health promotion interventions. Against this background, it is likely that teachers' disengagement, lack of motivation, and frequent turnover described in publication 5 had resulted in a gradual decline in programme implementation and, arguably, its eventual discontinuation. Indeed, Kahts-Kramer and Wood (2023) noted that predefined professional development training does not result in sustainable improvements in physical education teaching in disadvantaged South African schools. In line with this, Cook et al. (2019) posit that collaborative professional learning should include continuous training, ongoing consultation, and regular reminders to implementers as effective and necessary strategies to sustain school-based practices. Shoesmith et al. (2021) have also reiterated the importance of continuous communication between schools and project partners to foster programme maintenance. Hence, the reliance on external support and insufficient interaction with the research team identified in the reports from school personnel further support our assumption.

Importantly, Shoesmith et al. (2021) also point to the lack of executive support to integrate interventions within the school as a key obstacle to programme sustainment. Therefore, the authors advocate not only for staff engagement but also administrative involvement. Accordingly, the prospect of resuming *KaziKidz* activities post-pandemic presents uncertainties, as it would depend on schools taking autonomous initiative. However, the detected absence of programme ownership and executive management further undermine the feasibility of this event. Ultimately, it is reasonable to argue that the programme endorsement needed by the school administration should be elevated to higher levels of authority to facilitate the institutionalisation and continuity of school-based interventions.

These findings endorse the notion that continuous professional learning should actively encourage programme ownership among school staff and be accompanied by a sustainable support system both within the school (executive management commitment) and externally (regular coaching, policy actions). These measures would contribute to foster the sustainability of interventions and their effects in under-resourced schools in South Africa.

8.3. Strengths and limitations

The main strength of this thesis lies in the combination of multiple study designs to comprehensively understand the impact and implementation of the *KaziKidz* intervention in real-world contexts. The quantitative assessments delved into the associations between physical activity constructs and cardiometabolic parameters among South African school-aged children. Considering the discord between device-measured and self-reported physical activity (Marasso et al., 2021), a nuanced relationship was unveiled, which allowed for a more thorough interpretation of the intervention's effects on NCD risk factors. In turn, this newfound understanding revealed valuable insights for targeted interventions to influence children's behaviours and cardiovascular health in these settings. Simultaneously, the qualitative evaluation encompassed the lived experiences of diverse *KaziKidz* stakeholders. Their reported acceptability and perceived feasibility helped contextualise the observed health outcomes. In that regard, one of the achievements of this thesis was engaging caregivers in the discussions despite challenges with their involvement in these communities (de Villiers et al., 2015). Moreover, the convergence of these disparate outcomes leverages established methodologies, specifically a mixed-methods design (Creswell & Plano Clark, 2017) and the RE-AIM framework from implementation science (Glasgow, 1999). The quantitative RE-AIM evaluation, as outlined in the protocol, has been developed in this thesis to integrate the mixed-methods approach within the framework (Glasgow et al., 2019). By expanding the efficacy and effectiveness assessment to account for contextual interactions, the complexity of the intervention could be better grasped (Draper et al., 2023; Skivington et al., 2021). The questions included in this thesis were deemed pivotal for the intervention's trajectory, while contributing further to the emerging field of implementation science, especially within the physical activity domain.

Another important strength of this thesis is its longitudinal design spanning nearly three years. Throughout this period, children partook in the *KaziKidz* intervention, likely underwent sexual maturation, and experienced significant disturbances to their daily routines due to the COVID-19 pandemic. Consequently, the evaluation of the intervention captured critical events in children's lives under real-world circumstances, hence presenting a realistic portrayal of the challenges and opportunities for promoting healthy lifestyles among school-aged children from disadvantaged communities in South Africa. Along these lines, a further strength of this thesis was incorporating

measurements both pre- and post-pandemic of children's physical activity and cardiometabolic outcomes. Thereby, our findings contribute to the scarce literature on the COVID-19 pandemic's impact on the cardiovascular risk of South African children. However, the limited evidence regarding compliance with lockdown measures and subsequent consequences for children in these settings preclude definitive conclusions (United Nations Children's Fund (UNICEF), 2021). This thesis hence addressed important research gaps concerning learners in a vulnerable position. Particularly, it shed light on the underrepresentation of African children in international guidelines and their inconsistent application to identify cardiometabolic risk in the region. Importantly, this thesis focused on children exhibiting enhanced cardiovascular risk. As our findings revealed, this distinction holds significance since child subgroups responded differently to the intervention and displayed an adverse development of said risk.

However, this thesis has limitations that need consideration. First of all, the implementation of *KaziKidz* in the intervention schools was not monitored. In other words, there was a lack of evidence regarding the extent (dose) and quality (fidelity) of the intervention's delivery, including details such as participating classes, lessons per week, or terms per school year. Limited resources and the wish to avoid power dynamics between the research team and the schools drove this decision. Still, the assessment of implementation fidelity is crucial for making claims about the adequacy (Nally et al., 2021) or inadequacy (Love et al., 2019) of school-based interventions. Hence, this thesis cannot draw definitive inferences between intervention design, implementation strategies, and their efficacy. To address this gap, the intervention's acceptability and feasibility as reported by the deliverers were examined post hoc, shedding light on the willingness and capacity of schools to deploy the intervention as intended. Thereby, potential implementation variations among schools were unveiled. Nevertheless, it should be acknowledged that these reports reflect the perceived feasibility of the intervention rather than its objective assessment, which typically precedes the implementation phase (Proctor et al., 2011). Additionally, by prioritising specific implementation aspects guided by the RE-AIM framework and their perceived significance, the intervention's complexity might have not been fully captured. Indeed, a significant constrain of this thesis was the outbreak of the COVID-19 pandemic between the implementation and sustainability phases. As a result of school closures, the intervention was discontinued, thereby impeding the study of *KaziKidz*'s effectiveness and maintenance under normal circumstances.

Furthermore, participation bias might partly exist. This may be because school principals volunteered to participate in the *KaziBantu* project, which indicates an inherent interest in the programme. Nonetheless, this argument is contested by the fact that the teachers, who did not partake in the decision, were responsible for implementing the intervention and required to attend *KaziKidz* workshops. In that regard, contrasting the experiences of interviewed teachers participating in the workshops with those not interviewed, and who were assisted by a coach, could have offered valuable insights into the acceptance and utility of these workshops compared to a facilitator. Yet, the inclusion of three schools with differing implementation strategies, including two with either no or full support, was deemed appropriate to obtain a comprehensive analysis of the obstacles faced by these teachers. A further limitation of this thesis lies in the substantial reduction in sample size from post-intervention to follow-up. This drop originates from the relatively long follow-up and consequent graduation of learners from school, as well as the focus on children at increased risk for NCDs. Including healthy counterparts in the longitudinal study could have allowed for comparisons of long-term cardiovascular outcomes across subgroups, yet this option was constrained by time and financial resources. Lastly, the cross-sectional nature of publications 1 and 2 prevents elucidating causal relationships between elevated blood pressure and future risk of CVDs, and between physical activity constructs and cardiometabolic markers, respectively. Therefore, caution is warranted when interpreting the mechanisms underlying the intervention's impact on and between physical activity behaviours and cardiometabolic health.

8.4. Perspectives

8.4.1. Research implications

There is a need to define optimal levels of risk factors for NCDs in childhood that predict cardiovascular health later in life. To that end, accurate measurements of these risk factors, including physical inactivity, obesity, elevated blood pressure, dyslipidaemia, and increased glycaemia in African children, and specifically in South Africa, are imperative. Longitudinal population studies are required to investigate the association of diverse metrics and instruments for each variable with long-term health outcomes in this population. This will allow to identify the most suitable methodologies and evidence-based cut points that determine paediatric risk, thus facilitating informed decisions regarding the adoption of effective health promotion interventions.

In assessing the efficacy of *KaziKidz*, future research should aim to discern the aspects of the intervention that proved effective for different subgroups, particularly girls. In addition, there is a need to identify unmet needs among boys to enhance their physical activity levels and among at-risk children to improve cardiovascular outcomes. For example, the PAQ-C could be used to compare the types, distribution, and settings that favour physical activity between boys and girls. Increasing the understanding of the correlations between physical activity constructs and CVD risk factors through epidemiological studies could also help improve outcomes for subgroups at risk. Moreover, sedentary behaviours should be included in future analyses together with strategies to reduce its burden.

Importantly, monitoring the future delivery of *KaziKidz* in schools is crucial to ascertain dose and fidelity and to make final inferences. Indeed, implementation trials should be conducted throughout the intervention's life cycle, including the sustainability and dissemination phases, as adaptation may be required for *KaziKidz* to work effectively over time and be deployed with fidelity in new settings. Similarly, the evaluation of *KaziKidz*'s effectiveness upon its resumption remains relevant, encompassing both children with and without adverse cardiovascular profiles.

Finally, given that the teaching material alone did not yield the desired outcomes in terms of effectiveness and acceptability, evidence should be gathered on the impact of *KaziKidz*'s in-service teacher workshops and coaching on measures of intervention implementation, specifically feasibility, acceptance, fidelity, and adoption. For instance, a feasibility study with few schools could aim to co-design a comprehensive support strategy considering factors such as workshop format, mentoring, follow-up visits frequency, and other forms of facilitation. Economic evaluation of these implementation strategies is recommended as part of feasibility and sustainability studies.

8.4.2. Practical implications

Publication 5 offered a set of recommendations to foster the acceptance, uptake, penetration, maintenance, and ultimately, the effectiveness of *KaziKidz* and other school-based interventions in comparable low-income settings (Figure 4).

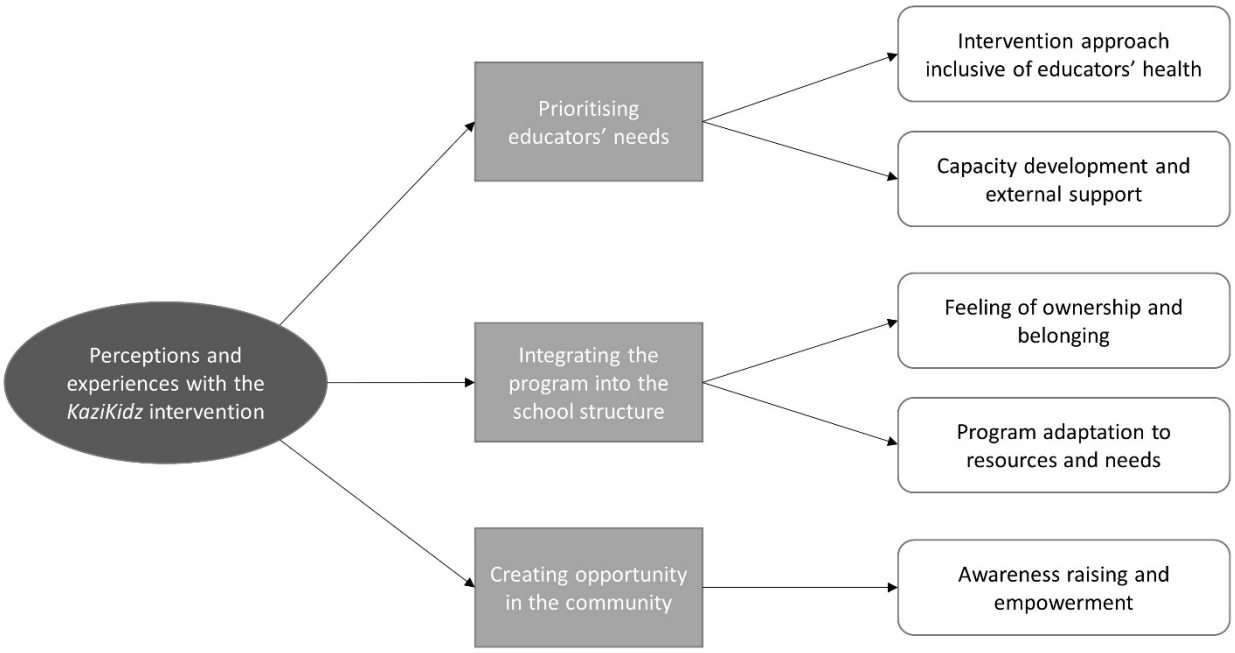

Figure 4. Recommended strategies to increase uptake and maintenance of health promotion interventions in schools based on stakeholders' reported perceptions and experiences.

One key strategy identified in this thesis centres on redefining the approach to the in-service teacher training and coaching. In the *KaziKidz* context, professional development takes the form of Short Learning Programmes (SLPs) accredited by the South African Council for Educators. These workshops foster physical education content and pedagogical knowledge among generalist educators, while providing them with freely available educational materials. The findings of this thesis advocate however for a stronger participatory approach to SLPs, whereby teachers are encouraged to take accountability of their own teaching. The goal hence should be for teachers to determine the priorities for the instruction of physical and health education in their schools and align the programme accordingly. To this end, we identified a need for direct ongoing support, including mentoring during the initial stages of programme implementation in the schools, followed by outreach visits to ensure maintenance and assess the need for adaptations.

Another critical tactic to amplify the intervention's effectiveness involves tackling the family and community environments. School-based measures should be accompanied by strategies that raise awareness and accountability in the community, such as educational meetings and resources for home use.

Furthermore, it is important to recognise the presence of other programmes in the region. Akin to the *Siyaphakama* Zwide schools project, which emerges from a partnership between *KaziBantu* and the Kolisi Foundation, United Through Sport, and Ubuntu Pathways, we propose closer collaboration with other partners in the field, including higher education institutions. These strategic alliances would enable to harness each other's expertise and create a more cohesive and sustainable approach to school-based physical activity interventions in South Africa.

8.4.3. Policy implications

Despite optimisation of interventions and their implementation, evidence-based practices will not lead to meaningful population impact in the absence of supportive policy environments. In turn, political engagement is needed for the implementation of such policies through matching actions. The accreditation of *KaziKidz*'s SLPs for the continued professional development of South African educators is an important example of a political instrument that facilitates programme institutionalisation, thereby contributing to its feasibility and sustainability. However, enabling teachers' participation in SLPs will not necessarily translate into personal initiative to implement the programme in the schools, especially without an accompanying support system.

Here, an opportunity arises for the government to further support Life Skills and Life Orientation teachers in building upon the competences acquired through SLPs by establishing a system of *KaziKidz* coaches. In South Africa, the outsourcing of physical education teaching to specialised service providers and the sustainability of this approach is subject to debate. While wealthier schools can afford to contract qualified coaches, schools of lower quintile depend on nongovernmental organisations and local community youth for these services (Burnett, 2020). In low-income schools, this practice often results in the provision of physical activities rather than quality physical education and a void when these external agencies cease their operations. Nonetheless, our findings highlight the advantages and necessity of assisting generalist educators in establishing health and physical activity interventions in schools, particularly in low-income areas, without advocating for a complete substitution of its delivery. Instead, this support should be integrated into the national education system as part of in-service professional development for teachers.

Moreover, the adequacy of *KaziKidz*'s components for specific subgroups of children can inform public health priorities to combat physical inactivity in the region. For instance, implementing

policy actions that incorporate a gender-responsive approach to physical activity interventions in South Africa could help dismantle barriers to physical activity and sports among adolescent girls and enhance their participation in these activities.

Lastly, the COVID-19 pandemic underscores the need for systems-wide strategies to address complex issues like physical inactivity and NCDs. It becomes essential that local political agendas prioritise physical activity in their post-pandemic recovery plans, thereby fostering a healthier future. For that purpose, it is crucial to acknowledge the significance of reintroducing physical education as a stand-alone subject taught by specialist teachers to drive systemic change. Encouragingly, a recent joint declaration by the South African Sports Minister, Zizi Kodwa, and the Basic Education Representative, Sifisi Ngobese, signals a positive step towards the reinstatement of physical education in the South African school curriculum.

8.5. Conclusion

This thesis offers valuable knowledge regarding the impact, implementation, and sustainability of the *KaziKidz* health promotion programme, aimed at enhancing physical activity and overall health among children in underprivileged primary schools in peri-urban areas of South Africa. The findings underscore the pivotal role of the school setting as an effective platform for delivering physical education, increasing physical activity levels, and instilling healthy behaviours among children from disadvantaged communities.

This thesis has not only shed light on *KaziKidz*'s mechanisms of action but also identified research gaps in the target population. The programme was particularly suitable in addressing disparities in physical activity participation. Concretely, it increased MVPA levels among girls, who initially displayed lower activity levels, higher sedentary time, and elevated cardiovascular risk compared to boys. Importantly, girls from lower-income areas in South Africa predominantly rely on school hours to engage in physical activities, especially those of higher intensities. The intervention also improved the mean arterial pressure and lipid and glucose profiles of healthy children, lacking however positive outcomes among certain high-risk sub-populations. Furthermore, enhanced school-time MVPA did not translate into increased activity across the day, nor did it result in a significant reduction in adiposity. Consequently, efforts are still needed to further rise MVPA levels during school hours for both girls and boys. To that end, evidence should be gathered around *KaziKidz*'s gender-specific approach and the different components targeting cardiovascular risk,

including aspects like sedentary and dietary behaviours. Yet, an underrepresentation of African children in international guidelines and their unstandardised application hinders interpretation of the true clinical significance of the interventions' effects. Hence, future research should focus on developing evidence-based definitions for paediatric cardiovascular risk.

Moreover, our findings have important implications for refining and expanding the future implementation and dissemination of *KaziKidz*. Stakeholder feedback revealed positive attitudes towards the programme, demonstrating a desire to reinforce physical education and physical activity in these contexts. However, teachers emphasised the importance of adopting a more inclusive approach along with support to implement *KaziKidz*'s educational materials. Hence, a need exists for a participatory professional development to enhance programme ownership, followed by personal coaching for effective delivery and ongoing support for maintenance. Caregivers also expressed a wish to be involved and informed about ways to support their children's participation and health. Strengthening school-based programmes like *KaziKidz* with community-focused strategies is crucial, especially in settings where safety concerns, cultural norms, and inadequate facilities hinder physical activity.

Finally, the findings presented in this thesis carry the potential to guide local policy efforts aimed at supporting sustainable physical education, physical activity participation, and overall health among South African children. The COVID-19 pandemic and subsequent school closures led to the discontinuation of *KaziKidz*, underscoring the challenges of programme sustainability in real-world contexts, particularly in resourced-constrained areas. Furthermore, a decline in cardiovascular health among at-risk children over time was observed, likely exacerbated by pandemic-related lockdown measures. In the current context, joint efforts from the schools, research team, and local authorities are imperative to resume *KaziKidz*'s activities in the schools, monitor programme delivery, assess the feasibility of different implementation strategies, and analyse the long-term maintenance of positive effects. School management and government accountability are vital to support the implementation and sustainability of school-based health-promoting initiatives like *KaziKidz*.

References

Abbas, S. A., Athar, S., & Jilani, N. Z. (2023). The Impact of the COVID-19 Pandemic on the Physical and Mental Health of School-Aged Children. *HCA Healthc J Med*, *4*(3), 223-228. https://doi.org/10.36518/2689-0216.1547

Adom, T., De Villiers, A., Puoane, T., & Kengne, A. P. (2019). School-Based Interventions Targeting Nutrition and Physical Activity, and Body Weight Status of African Children: A Systematic Review. *Nutrients*, *12*(1). https://doi.org/10.3390/nu12010095

Agbo, H. A., Zoakah, A. I., Isichei, C. O., Sagay, A. S., Achenbach, C. J., & Okeahialam, B. N. (2020). Cardiovascular Anthropometry: What Is Best Suited for Large-Scale Population Screening in Sub-Saharan Africa? *Front Cardiovasc Med*, *7*, 522123. https://doi.org/10.3389/fcvm.2020.522123

Agirbasli, M., Dilek, H. F., Tatlisu, M. A., & Ankarali, H. (2020). Reliability of normative tables in assessing elevated blood pressure in children. *J Hum Hypertens*, *34*(3), 241-247. https://doi.org/10.1038/s41371-019-0290-z

Agyepong, I. A., Sewankambo, N., Binagwaho, A., Coll-Seck, A. M., Corrah, T., Ezeh, A., Fekadu, A., Kilonzo, N., Lamptey, P., Masiye, F., Mayosi, B., Mboup, S., Muyembe, J. J., Pate, M., Sidibe, M., Simons, B., Tlou, S., Gheorghe, A., Legido-Quigley, H., . . . Piot, P. (2017). The path to longer and healthier lives for all Africans by 2030: the Lancet Commission on the future of health in sub-Saharan Africa. *Lancet*, *390*(10114), 2803-2859. https://doi.org/10.1016/S0140-6736(17)31509-X

Aibar, A., Bois, J. E., Zaragoza, J., Generelo, E., Julián, J. A., & Paillard, T. (2014). Do epoch lengths affect adolescents' compliance with physical activity guidelines? *J Sports Med Phys Fitness*, *54*(3), 326-334. http://europepmc.org/abstract/MED/24739295

Ajala, O., Mold, F., Boughton, C., Cooke, D., & Whyte, M. (2017). Childhood predictors of cardiovascular disease in adulthood. A systematic review and meta-analysis. *Obes Rev*, *18*(9), 1061-1070. https://doi.org/10.1111/obr.12561

American Diabetes Association. (2020). 2. Classification and Diagnosis of Diabetes: Standards of Medical Care in Diabetes-2020. *Diabetes Care*, *43*(Suppl 1), S14-S31. https://doi.org/10.2337/dc20-S002

Amnesty International. (2020). Broken and unequal: The state of education in South Africa.

Andersen, L. B., Lauersen, J. B., Brond, J. C., Anderssen, S. A., Sardinha, L. B., Steene-Johannessen, J., McMurray, R. G., Barros, M. V., Kriemler, S., Moller, N. C., Bugge, A., Kristensen, P. L., Ried-Larsen, M., Grontved, A., & Ekelund, U. (2015). A new approach to define and diagnose cardiometabolic disorder in children. *J Diabetes Res*, *2015*, 539835. https://doi.org/10.1155/2015/539835

Anderson, E., & Durstine, J. L. (2019). Physical activity, exercise, and chronic diseases: A brief review. *Sports Med Health Sci*, *1*(1), 3-10. https://doi.org/10.1016/j.smhs.2019.08.006

References

Armstrong, M. E., Lambert, M. I., & Lambert, E. V. (2011). Secular trends in the prevalence of stunting, overweight and obesity among South African children (1994-2004). *Eur J Clin Nutr*, *65*(7), 835-840. https://doi.org/10.1038/ejcn.2011.46

Arslanian, S., Bacha, F., Grey, M., Marcus, M. D., White, N. H., & Zeitler, P. (2018). Evaluation and Management of Youth-Onset Type 2 Diabetes: A Position Statement by the American Diabetes Association. *Diabetes Care*, *41*(12), 2648-2668. https://doi.org/10.2337/dci18-0052

Aubert, S., Brazo-Sayavera, J., Gonzalez, S. A., Janssen, I., Manyanga, T., Oyeyemi, A. L., Picard, P., Sherar, L. B., Turner, E., & Tremblay, M. S. (2021). Global prevalence of physical activity for children and adolescents; inconsistencies, research gaps, and recommendations: a narrative review. *Int J Behav Nutr Phys Act*, *18*(1), 81. https://doi.org/10.1186/s12966-021-01155-2

Azegami, T., Uchida, K., Tokumura, M., & Mori, M. (2021). Blood Pressure Tracking From Childhood to Adulthood. *Front Pediatr*, *9*, 785356. https://doi.org/10.3389/fped.2021.785356

Bailey R, W. I., Dismore H. (2004). Girls' participation in physical activities and sports: benefits, patterns, influences and ways forward. http://www.richardbailey.net/Girlssport.pdf

Balder, J. W., Lansberg, P. J., Hof, M. H., Wiegman, A., Hutten, B. A., & Kuivenhoven, J. A. (2018). Pediatric lipid reference values in the general population: The Dutch lifelines cohort study. *J Clin Lipidol*, *12*(5), 1208-1216. https://doi.org/10.1016/j.jacl.2018.05.011

Barbosa Filho, V. C., Minatto, G., Mota, J., Silva, K. S., de Campos, W., & Lopes Ada, S. (2016). Promoting physical activity for children and adolescents in low- and middle-income countries: An umbrella systematic review: A review on promoting physical activity in LMIC. *Prev Med*, *88*, 115-126. https://doi.org/10.1016/j.ypmed.2016.03.025

Bauman, A. E., Reis, R. S., Sallis, J. F., Wells, J. C., Loos, R. J., Martin, B. W., & Lancet Physical Activity Series Working, G. (2012). Correlates of physical activity: why are some people physically active and others not? *Lancet*, *380*(9838), 258-271. https://doi.org/10.1016/S0140-6736(12)60735-1

Biddle, S. J. H., Gorely, T., Pearson, N., & Bull, F. C. (2011). An assessment of self-reported physical activity instruments in young people for population surveillance: Project ALPHA. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 1. https://doi.org/10.1186/1479-5868-8-1

Bloom, D. E., Cafiero, E. T., Jané-Llopis, E., Abrahams-Gessel, S., Bloom, L. R., Fathima, S., Feigl, A. B., Gaziano, T., Mowafi, M., Pandya, A., Prettner, K., Rosenberg, L.,, Seligman, B., Stein, A. Z., & Weinstein, C. (2011). The Global Economic Burden of Noncommunicable Diseases. *Geneva: World Economic Forum*. https://www3.weforum.org/docs/WEF_Harvard_HE_GlobalEconomicBurdenNonCommunicableDiseases_2011.pdf

References

Bodkin, A., & Hakimi, S. (2020). Sustainable by design: a systematic review of factors for health promotion program sustainability. *BMC Public Health*, *20*(1), 964. https://doi.org/10.1186/s12889-020-09091-9

Bradshaw, D., Nannan, N. N., Pillay-van Wyk, V., Laubscher, R., Groenewald, P., & Dorrington, R. E. (2019). Burden of disease in South Africa: Protracted transitions driven by social pathologies. *S Afr Med J*, *109*(11b), 69-76. https://doi.org/10.7196/SAMJ.2019.v109i11b.14273

Bradshaw, D., Norman, R., Lewin, S., Joubert, J., Schneider, M., Nannan, N., Groenewald, P., Laubscher, R., Matzopoulos, R., Nojilana, B., Pieterse, D., Steyn, K., & Vos, T. (2007). Strengthening public health in South Africa: building a stronger evidence base for improving the health of the nation. *S Afr Med J*, *97*(8 Pt 2), 643-649.

Brand, R., & Ekkekakis, P. (2017). Affective–Reflective Theory of physical inactivity and exercise. *German Journal of Exercise and Sport Research*, *48*(1), 48-58. https://doi.org/10.1007/s12662-017-0477-9

Broyles, S. T., Denstel, K. D., Church, T. S., Chaput, J. P., Fogelholm, M., Hu, G., Kuriyan, R., Kurpad, A., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tremblay, M. S., Tudor-Locke, C., Zhao, P., . . . Group, I. R. (2015). The epidemiological transition and the global childhood obesity epidemic. *Int J Obes Suppl*, *5*(Suppl 2), S3-8. https://doi.org/10.1038/ijosup.2015.12

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., . . . Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*, *54*(24), 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Burnett, C. (2020). A national study on the state and status of physical education in South African public schools. *Physical Education and Sport Pedagogy*, *26*(2), 179-196. https://doi.org/10.1080/17408989.2020.1792869

Cairney, J., Kwan, M. Y. W., Velduizen, S., Hay, J., Bray, S. R., & Faught, B. E. (2012). Gender, perceived competence and the enjoyment of physical education in children: a longitudinal examination. *International Journal of Behavioral Nutrition and Physical Activity*, *9*(1), 26. https://doi.org/10.1186/1479-5868-9-26

Cárcamo, C., Moreno, A., & del Barrio, C. (2020). Girls Do Not Sweat: the Development of Gender Stereotypes in Physical Education in Primary School. *Human Arenas*, *4*(2), 196-217. https://doi.org/10.1007/s42087-020-00118-6

Carney, R., & Firth, J. (2021). Exercise interventions in child and adolescent mental health care: An overview of the evidence and recommendations for implementation. *JCPP Adv*, *1*(4), e12031. https://doi.org/10.1002/jcv2.12031

Carson, R. L., Castelli, D. M., Beighle, A., & Erwin, H. (2014). School-based physical activity promotion: a conceptual framework for research and practice. *Child Obes*, *10*(2), 100-106. https://doi.org/10.1089/chi.2013.0134

References

Cassar, S., Salmon, J., Timperio, A., Naylor, P. J., van Nassau, F., Contardo Ayala, A. M., & Koorts, H. (2019). Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. *Int J Behav Nutr Phys Act*, *16*(1), 120. https://doi.org/10.1186/s12966-019-0876-4

Cassimos, C. H., Varlamis, G., Karamperis, S., & Katsouyannopoulos, V. (1977). BLOOD PRESSURE IN CHILDREN AND ADOLESCENTS. *Acta Paediatrica*, *66*(4), 439-443. https://doi.org/https://doi.org/10.1111/j.1651-2227.1977.tb07924.x

Cena, H., Fiechtner, L., Vincenti, A., Magenes, V. C., De Giuseppe, R., Manuelli, M., Zuccotti, G. V., & Calcaterra, V. (2021). COVID-19 Pandemic as Risk Factors for Excessive Weight Gain in Pediatrics: The Role of Changes in Nutrition Behavior. A Narrative Review. *Nutrients*, *13*(12). https://doi.org/10.3390/nu13124255

Centers for Disease Control and Prevention. (2000). CDC growth charts: United States. . *Hyattsville, Maryland: National Center for Health Statistics*. Retrieved 10 July 2023 from www.cdc.gov/growthcharts

Cheung, P. (2017). School-based physical activity opportunities in PE lessons and after-school hours: Are they associated with children's daily physical activity? *European Physical Education Review*, *25*(1), 65-75. https://doi.org/10.1177/1356336x17705274

Chinapaw, M. J. M. M., Lidwine B. van Poppel, Mireille N.M. van Mechelen, Willem Terwee, Caroline B. . (2010). Physical Activity Questionnaires for Youth: A Systematic Review of Measurement Properties. *Sports Medicine*, *40*(7), 539-563. https://doi.org/https://doi.org/10.2165/11530770-000000000-00000

Christian, D. L., Todd, C., Rance, J., Stratton, G., Mackintosh, K. A., Rapport, F., & Brophy, S. (2020). Involving the headteacher in the development of school-based health interventions: A mixed-methods outcome and process evaluation using the RE-AIM framework. *PLoS One*, *15*(4), e0230745. https://doi.org/10.1371/journal.pone.0230745

Cleland, V., Tian, J., Buscot, M. J., Magnussen, C. G., Bazzano, L., Burns, T. L., Daniels, S., Dwyer, T., Hutri-Kahonen, N., Ikonen, J., Jacobs, D., Juonala, M., Prineas, R., Raitakari, O., Sinaiko, A., Steinberger, J., Urbina, E. M., Woo, J. G., & Venn, A. (2022). Body-mass index trajectories from childhood to mid-adulthood and their sociodemographic predictors: Evidence from the International Childhood Cardiovascular Cohort (i3C) Consortium. *EClinicalMedicine*, *48*, 101440. https://doi.org/10.1016/j.eclinm.2022.101440

Climie, R. E., Park, C., Avolio, A., Mynard, J. P., Kruger, R., & Bruno, R. M. (2021). Vascular Ageing in Youth: A Call to Action. *Heart Lung Circ*, *30*(11), 1613-1626. https://doi.org/10.1016/j.hlc.2021.06.516

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes*, *7*(4), 284-294. https://doi.org/10.1111/j.2047-6310.2012.00064.x

Cook, C. R., Lyon, A. R., Locke, J., Waltz, T., & Powell, B. J. (2019). Adapting a Compilation of Implementation Strategies to Advance School-Based Implementation Research and Practice. *Prev Sci*, *20*(6), 914-935. https://doi.org/10.1007/s11121-019-01017-1

Coovadia, H., Jewkes, R., Barron, P., Sanders, D., & McIntyre, D. (2009). The health and health system of South Africa: historical roots of current public health challenges. *Lancet*, *374*(9692), 817-834. https://doi.org/10.1016/S0140-6736(09)60951-X

Corder, K., Winpenny, E., Love, R., Brown, H. E., White, M., & Sluijs, E. V. (2019). Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. *Br J Sports Med*, *53*(8), 496-503. https://doi.org/10.1136/bjsports-2016-097330

Creswell, J. W., & Plano Clark, V. L. (2017). Core Mixed Methods Designs. In *Designing and Conducting Mixed Methods Research* (3 ed., pp. 50). SAGE Publications, Inc. https://us.sagepub.com/en-us/nam/designing-and-conducting-mixed-methods-research/book241842

Curran, G. M. (2020). Implementation science made too simple: a teaching tool. *Implement Sci Commun*, *1*, 27. https://doi.org/10.1186/s43058-020-00001-z

da Silva Bandeira, A., Pizani, J., de Sousa, A., da Silva, J. A., Minatto, G., Barbosa Filho, V. C., & Silva, K. S. (2022). Implementation of a school-based physical activity intervention for Brazilian adolescents: a mixed-methods evaluation. *Health Promot Int*, *37*(2). https://doi.org/10.1093/heapro/daab091

Darlington, E. J., Violon, N., & Jourdan, D. (2018). Implementation of health promotion programmes in schools: an approach to understand the influence of contextual factors on the process? *BMC Public Health*, *18*(1), 163. https://doi.org/10.1186/s12889-017-5011-3

de Ferranti, S. D., Steinberger, J., Ameduri, R., Baker, A., Gooding, H., Kelly, A. S., Mietus-Snyder, M., Mitsnefes, M. M., Peterson, A. L., St-Pierre, J., Urbina, E. M., Zachariah, J. P., & Zaidi, A. N. (2019). Cardiovascular Risk Reduction in High-Risk Pediatric Patients: A Scientific Statement From the American Heart Association. *Circulation*, *139*(13), e603-e634. https://doi.org/10.1161/CIR.0000000000000618

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ*, *85*(9), 660-667. https://doi.org/10.2471/blt.07.043497

de Villiers, A., Steyn, N. P., Draper, C. E., Fourie, J. M., Barkhuizen, G., Lombard, C. J., Dalais, L., Abrahams, Z., & Lambert, E. V. (2012). "HealthKick": Formative assessment of the health environment in low-resource primary schools in the Western Cape Province of South Africa. *BMC Public Health*, *12*(1), 794. https://doi.org/10.1186/1471-2458-12-794

de Villiers, A., Steyn, N. P., Draper, C. E., Hill, J., Dalais, L., Fourie, J., Lombard, C., Barkhuizen, G., & Lambert, E. V. (2015). Implementation of the HealthKick intervention in primary schools in low-income settings in the Western Cape Province, South Africa: a process evaluation. *BMC Public Health*, *15*, 818. https://doi.org/10.1186/s12889-015-2157-8

Della Corte, K., Fife, J., Gardner, A., Murphy, B. L., Kleis, L., Della Corte, D., Schwingshackl, L., LeCheminant, J. D., & Buyken, A. E. (2021). World trends in sugar-sweetened beverage and dietary sugar intakes in children and adolescents: a systematic review. *Nutr Rev*, *79*(3), 274-288. https://doi.org/10.1093/nutrit/nuaa070

References

Department of Basic Education. (2011a). *National Curriculum Statement: Curriculum and Assessment Policy Statement (CAPS). Life Orientation Senior phase Grades 7-9* Pretoria, South Africa: Department of Basic Education Retrieved from https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20SP%20%20LIFE%20ORIENTATION%20%20WEB.pdf?ver=2015-01-27-160145-607

Department of Basic Education. (2011b). *National Curriculum Statement: Curriculum and Assessment Policy Statement (CAPS). Life Skills Foundation phase Grades R-3*. Pretoria, South Africa: Department of Basic Education Retrieved from https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20Life%20Skills%20%20English%20_%20Gr%20R-3%20FS.pdf?ver=2015-01-27-162204-953

Department of Basic Education. (2011c). *National Curriculum Statement: Curriculum and Assessment Policy Statement (CAPS). Life Skills Intermediate phase Grades 4-6*. Pretoria, South Africa: Department of Basic Education Retrieved from https://www.education.gov.za/Portals/0/CD/National%20Curriculum%20Statements%20and%20Vocational/CAPS%20IP%20%20LIFE%20SKILLS%20GR%204-6%20%20WEB.pdf?ver=2015-01-27-161425-333

Department of Education. (1997). *Curriculum 2005: lifelong learning for the 21st century*. Pretoria, South Africa: Department of Education

Ding, D., Ramirez Varela, A., Bauman, A. E., Ekelund, U., Lee, I. M., Heath, G., Katzmarzyk, P. T., Reis, R., & Pratt, M. (2020). Towards better evidence-informed global action: lessons learnt from the Lancet series and recent developments in physical activity and public health. *Br J Sports Med*, *54*(8), 462-468. https://doi.org/10.1136/bjsports-2019-101001

Dixon, K., Excell, L., & Linington, V. (2014). We are workshopped: problematising Foundation Phase teachers' identity constructions. *South African Journal of Childhood Education*, *4*(1), 17. https://doi.org/https://doi.org/10.4102/sajce.v4i1.60

Dolley, D., du Randt, R., Gerber, M., Pühse, U., Bosma, J., Arnaiz, P., Aerts, A., Adams, L., Degen, J., Joubert, N., Müller, I., Nqweniso, S., Seelig, H., Steinmann, P., Utzinger, J., & Walter, C. (2023a). Effect of the KaziBantu school-based health intervention on non-communicable disease risk factors of children from low-income schools in Gqeberha, South Africa. *African Journal for Physical Activity and Health Sciences*, *29*(4).

Dolley, D., Walter, C., du Randt, R., Pühse, U., Bosma, J., Aerts, A., Adams, L., Arnaiz, P., Degen, J., Gall, S., Joubert, N., Müller, I., Nienaber, M., Nqweniso, F., Seelig, H., Steinmann, P., Utzinger, J., & Gerber, M. (2022). Clustered cardiovascular disease risk among children aged 8-13 years from lower socioeconomic schools in Gqeberha, South Africa. *BMJ Open Sport Exerc Med*, *8*(2), e001336. https://doi.org/10.1136/bmjsem-2022-001336

Donaldson, R. (2014). South African Township Transformation. In A. C. Michalos (Ed.), *Encyclopedia of Quality of Life and Well-Being Research* (pp. 6223-6228). Springer Netherlands. https://doi.org/10.1007/978-94-007-0753-5_4186

Draper, C. E., Davidowitz, K. J., & Goedecke, J. H. (2016). Perceptions relating to body size, weight loss and weight-loss interventions in black South African women: a qualitative study. *Public Health Nutr*, *19*(3), 548-556. https://doi.org/10.1017/S1368980015001688

Draper, C. E., de Kock, L., Grimsrud, A. T., Rudolph, M., Nemutandani, S., Kolbe-Alexander, T., & Lambert, E. V. (2010a). Evaluation of a school-based physical activity intervention in Alexandra Township. *South African Journal of Sports Medicine*, *22*(1), 12-19. https://doi.org/10.17159/2078-516X/2010/v22i1a320

Draper, C. E., de Villiers, A., Lambert, E. V., Fourie, J., Hill, J., Dalais, L., Abrahams, Z., & Steyn, N. P. (2010b). HealthKick: a nutrition and physical activity intervention for primary schools in low-income settings. *BMC Public Health*, *10*(1), 398. https://doi.org/10.1186/1471-2458-10-398

Draper, C. E., Thwala, N., Slemming, W., Lye, S. J., & Norris, S. A. (2023). Development, Implementation, and Process Evaluation of Bukhali: An Intervention from Preconception to Early Childhood. *Glob Implement Res Appl*, *3*(1), 31-43. https://doi.org/10.1007/s43477-023-00073-8

Draper, C. E., Tomaz, S. A., Bassett, S. H., Harbron, J., Kruger, H. S., Micklesfield, L. K., Monyeki, A., Lambert, E. V., & and members of the HAKSA 2018 Scientific Advisory Group. (2018). Results from the Healthy Active Kids South Africa 2018 Report Card. *S Afr J Child Health*, *13(3)*, 130-136. https://doi.org/http://www.sajch.org.za/index.php/SAJCH/article/view/1511

Drozdz, D., Alvarez-Pitti, J., Wojcik, M., Borghi, C., Gabbianelli, R., Mazur, A., Herceg-Cavrak, V., Lopez-Valcarcel, B. G., Brzezinski, M., Lurbe, E., & Wuhl, E. (2021). Obesity and Cardiometabolic Risk Factors: From Childhood to Adulthood. *Nutrients*, *13*(11). https://doi.org/10.3390/nu13114176

Duffey, K., Barbosa, A., Whiting, S., Mendes, R., Yordi Aguirre, I., Tcymbal, A., Abu-Omar, K., Gelius, P., & Breda, J. (2021). Barriers and Facilitators of Physical Activity Participation in Adolescent Girls: A Systematic Review of Systematic Reviews. *Front Public Health*, *9*, 743935. https://doi.org/10.3389/fpubh.2021.743935

Dumith, S. C., Gigante, D. P., Domingues, M. R., & Kohl, H. W., 3rd. (2011). Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol*, *40*(3), 685-698. https://doi.org/10.1093/ije/dyq272

Dzhambov, A. M., Lercher, P., Vincens, N., Persson Waye, K., Klatte, M., Leist, L., Lachmann, T., Schreckenberg, D., Belke, C., Ristovska, G., Kanninen, K. M., Botteldooren, D., Van Renterghem, T., Jeram, S., Selander, J., Arat, A., White, K., Julvez, J., Clark, C., . . . van Kamp, I. (2023). Protective effect of restorative possibilities on cognitive function and mental health in children and adolescents: A scoping review including the role of physical activity. *Environ Res*, *233*, 116452. https://doi.org/10.1016/j.envres.2023.116452

Eccles, M. P., & Mittman, B. S. (2006). Welcome to Implementation Science. *Implementation Science*, *1*(1). https://doi.org/10.1186/1748-5908-1-1

References

Errisuriz, V. L., Golaszewski, N. M., Born, K., & Bartholomew, J. B. (2018). Systematic Review of Physical Education-Based Physical Activity Interventions Among Elementary School Children. *J Prim Prev*, *39*(3), 303-327. https://doi.org/10.1007/s10935-018-0507-x

Expert Panel on Integrated Guidelines for Cardiovascular Health and Risk Reduction in Children and Adolescents, & National Heart Lung and Blood Institute. (2011). Expert panel on integrated guidelines for cardiovascular health and risk reduction in children and adolescents: summary report. *Pediatrics*, *128 Suppl 5*, S213-256. https://doi.org/10.1542/peds.2009-2107C

Fazeli Dehkordi, Z. S., Khatami, S. M., & Ranjbar, E. (2022). The Associations Between Urban Form and Major Non-communicable Diseases: a Systematic Review. *J Urban Health*, *99*(5), 941-958. https://doi.org/10.1007/s11524-022-00652-4

Flynn, J. T., Kaelber, D. C., Baker-Smith, C. M., Blowey, D., Carroll, A. E., Daniels, S. R., de Ferranti, S. D., Dionne, J. M., Falkner, B., Flinn, S. K., Gidding, S. S., Goodwin, C., Leu, M. G., Powers, M. E., Rea, C., Samuels, J., Simasek, M., Thaker, V. V., & Urbina, E. M. (2017). Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents. *Pediatrics*, *140*(3), e20171904. https://doi.org/10.1542/peds.2017-1904

The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents. (2004). *Pediatrics*, *114*(Supplement 2), 555. http://pediatrics.aappublications.org/content/114/Supplement_2/555.abstract

Frenk, J., Bobadilla, J. L., Sepúlveda, J., & López Cervantes, M. (1989). Health transition in middle-income countries: new challenges for health care. *Health Policy and Planning*, *4*(1), 29-39. https://doi.org/10.1093/heapol/4.1.29

Gall, S., Walter, C., du Randt, R., Adams, L., Joubert, N., Müller, I., Nqweniso, S., Pühse, U., Seelig, H., Smith, D., Steinmann, P., Utzinger, J., & Gerber, M. (2020). Changes in Self-Reported Physical Activity Predict Health-Related Quality of Life Among South African Schoolchildren: Findings From the DASH Intervention Trial. *Front Public Health*, *8*, 492618. https://doi.org/10.3389/fpubh.2020.492618

Garcia-Hermoso, A., Hormazabal-Aguayo, I., Gonzalez-Calderon, N., Russell-Guzman, J., Vicencio-Rojas, F., Chacana-Canas, C., Urrutia-Reyes, I., Ramirez-Velez, R., Alonso-Martinez, A. M., Izquierdo, M., & Fernandez-Vergara, O. (2020). Exercise program and blood pressure in children: The moderating role of sedentary time. *J Sci Med Sport*. https://doi.org/10.1016/j.jsams.2020.02.012

Gerber, M., Borjesson, M., Jonsdottir, I. H., & Lindwall, M. (2020). Association of change in physical activity associated with change in sleep complaints: results from a six-year longitudinal study with Swedish health care workers. *Sleep Med*, *69*, 189-197. https://doi.org/10.1016/j.sleep.2019.01.026

Gerber, M., Lang, C., Beckmann, J., du Randt, R., Long, K. Z., Muller, I., Nienaber, M., Probst-Hensch, N., Steinmann, P., Puhse, U., Utzinger, J., Nqweniso, S., & Walter, C. (2022). Physical Activity, Sedentary Behaviour, Weight Status, and Body Composition among

South African Primary Schoolchildren. *Int J Environ Res Public Health*, *19*(18). https://doi.org/10.3390/ijerph191811836

Gerber, M., Müller, I., Walter, C., du Randt, R., Adams, L., Gall, S., Joubert, N., Nqweniso, S., Smith, D., Steinmann, P., Probst-Hensch, N., Utzinger, J., & Pühse, U. (2018). Physical activity and dual disease burden among South African primary schoolchildren from disadvantaged neighbourhoods. *Prev Med*, *112*, 104-110. https://doi.org/10.1016/j.ypmed.2018.04.001

Giles-Corti, B., & Donovan, R. J. (2002). The relative influence of individual, social and physical environment determinants of physical activity. *Social Science & Medicine*, *54*(12), 1793-1812. https://doi.org/https://doi.org/10.1016/S0277-9536(01)00150-2

Glasgow, R. E., Harden, S. M., Gaglio, B., Rabin, B., Smith, M. L., Porter, G. C., Ory, M. G., & Estabrooks, P. A. (2019). RE-AIM Planning and Evaluation Framework: Adapting to New Science and Practice With a 20-Year Review. *Front Public Health*, *7*, 64. https://doi.org/10.3389/fpubh.2019.00064

Glasgow, R. E. V., T. M.; Boles S. M. (1999). Evaluating the public health impact of health promotion interventions the RE-AIM framework. *Am J Public Health*, *89(9)*, 1322-1327. https://doi.org/10.2105/ajph.89.9.1322

Global Burden of Disease 2017 Risk Factor Collaborators. (2018). Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet*, *392*(10159), 1923-1994. https://doi.org/10.1016/s0140-6736(18)32225-6

Global Burden of Disease 2019 Cardiovascular Diseases Writing Group. (2020). Global Burden of Cardiovascular Diseases and Risk Factors, 1990-2019: Update From the GBD 2019 Study. *J Am Coll Cardiol*, *76*(25), 2982-3021. https://doi.org/10.1016/j.jacc.2020.11.010

Goslin, A. E. (2020). Global perspectives and quality physical education (QPE) : stagnation or new paradigms? *African Journal for Physical Activity and Health Sciences (AJPHES)*, *26*(sup1_1), 1-15. https://doi.org/doi:10.37597/ajphes.2020.s.1

Gouda, H. N., Charlson, F., Sorsdahl, K., Ahmadzada, S., Ferrari, A. J., Erskine, H., Leung, J., Santamauro, D., Lund, C., Aminde, L. N., Mayosi, B. M., Kengne, A. P., Harris, M., Achoki, T., Wiysonge, C. S., Stein, D. J., & Whiteford, H. (2019). Burden of non-communicable diseases in sub-Saharan Africa, 1990–2017: results from the Global Burden of Disease Study 2017. *The Lancet Global Health*, *7*(10), e1375-e1387. https://doi.org/10.1016/s2214-109x(19)30374-2

Grydeland, M., Bjelland, M., Anderssen, S. A., Klepp, K. I., Bergh, I. H., Andersen, L. F., Ommundsen, Y., & Lien, N. (2014). Effects of a 20-month cluster randomised controlled school-based intervention trial on BMI of school-aged boys and girls: the HEIA study. *Br J Sports Med*, *48*(9), 768-773. https://doi.org/10.1136/bjsports-2013-092284

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys

with 1·6 million participants. *The Lancet Child & Adolescent Health*, *4*(1), 23-35. https://doi.org/10.1016/s2352-4642(19)30323-2

Hailemariam, M., Bustos, T., Montgomery, B., Barajas, R., Evans, L. B., & Drahota, A. (2019). Evidence-based intervention sustainability strategies: a systematic review. *Implement Sci*, *14*(1), 57. https://doi.org/10.1186/s13012-019-0910-6

Hanson, S. K., Munthali, R. J., Micklesfield, L. K., Lobelo, F., Cunningham, S. A., Hartman, T. J., Norris, S. A., & Stein, A. D. (2019). Longitudinal patterns of physical activity, sedentary behavior and sleep in urban South African adolescents, Birth-To-Twenty Plus cohort. *BMC Pediatr*, *19*(1), 241. https://doi.org/10.1186/s12887-019-1619-z

Hartwig, T. B., Sanders, T., Vasconcellos, D., Noetel, M., Parker, P. D., Lubans, D. R., Andrade, S., Avila-Garcia, M., Bartholomew, J., Belton, S., Brooks, N. E., Bugge, A., Cavero-Redondo, I., Christiansen, L. B., Cohen, K., Coppinger, T., Dyrstad, S., Errisuriz, V., Fairclough, S., . . . Del Pozo Cruz, B. (2021). School-based interventions modestly increase physical activity and cardiorespiratory fitness but are least effective for youth who need them most: an individual participant pooled analysis of 20 controlled trials. *Br J Sports Med*. https://doi.org/10.1136/bjsports-2020-102740

Haughton McNeill, L., Wyrwich, K. W., Brownson, R. C., Clark, E. M., & Kreuter, M. W. (2006). Individual, social environmental, and physical environmental influences on physical activity among black and white Adults: A Structural Equation Analysis. *Annals of Behavioral Medicine*, *31*(1), 36-44. https://doi.org/10.1207/s15324796abm3101_7

Haugland, E. S., Nilsen, A. K. O., Okely, A. D., Aadland, K. N., & Aadland, E. (2023). Multivariate physical activity association patterns for fundamental motor skills and physical fitness in preschool children aged 3-5 years. *J Sports Sci*, 1-14. https://doi.org/10.1080/02640414.2023.2232219

Hegarty, L. M., Mair, J. L., Kirby, K., Murtagh, E., & Murphy, M. H. (2016). School-based Interventions to Reduce Sedentary Behaviour in Children: A Systematic Review. *AIMS Public Health*, *3*(3), 520-541. https://doi.org/10.3934/publichealth.2016.3.520

Herlitz, L., MacIntyre, H., Osborn, T., & Bonell, C. (2020). The sustainability of public health interventions in schools: a systematic review. *Implement Sci*, *15*(1), 4. https://doi.org/10.1186/s13012-019-0961-8

Hickman, T. B., Briefel, R. R., Carroll, M. D., Rifkind, B. M., Cleeman, J. I., Maurer, K. R., & Johnson, C. L. (1998). Distributions and Trends of Serum Lipid Levels among United States Children and Adolescents Ages 4–19 Years: Data from the Third National Health and Nutrition Examination Survey. *Preventive Medicine*, *27*(6), 879-890. https://doi.org/https://doi.org/10.1006/pmed.1998.0376

Hill, J., Draper, C. E., Villiers, A. D., Fourie, J. M., Mohamed, S., Parker, W.-a., & Steyn, N. (2015). Promoting healthy lifestyle behaviour through the Life-Orientation curriculum: Teachers' perceptions of the HealthKick intervention. *South African Journal of Education*, *35*(1). http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S0256-01002015000100008&nrm=iso

Huang, Y., Chen, Z., Chen, B., Li, J., Yuan, X., Li, J., Wang, W., Dai, T., Chen, H., Wang, Y., Wang, R., Wang, P., Guo, J., Dong, Q., Liu, C., Wei, Q., Cao, D., & Liu, L. (2023). Dietary sugar consumption and health: umbrella review. *BMJ (Clinical research ed.)*, *381*, e071609. https://doi.org/10.1136/bmj-2022-071609

Hudda, M. T., Wells, J. C. K., Adair, L. S., Alvero-Cruz, J. R. A., Ashby-Thompson, M. N., Ballesteros-Vasquez, M. N., Barrera-Exposito, J., Caballero, B., Carnero, E. A., Cleghorn, G. J., Davies, P. S. W., Desmond, M., Devakumar, D., Gallagher, D., Guerrero-Alcocer, E. V., Haschke, F., Horlick, M., Ben Jemaa, H., Khan, A. I., . . . Nightingale, C. M. (2022). External validation of a prediction model for estimating fat mass in children and adolescents in 19 countries: individual participant data meta-analysis. *BMJ (Clinical research ed.)*, *378*, e071185. https://doi.org/10.1136/bmj-2022-071185

Institute for Health Metrics and Evaluation. (2020). GBD 2019 Cause and Risk Summary: Noncommunicable diseases. *Seattle, USA: Institute for Health Metrics and Evaluation, University of Washington*. Retrieved 24 June 2023 from https://www.healthdata.org/results/gbd_summaries/2019

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *7*(1), 40. https://doi.org/10.1186/1479-5868-7-40

Javed, A., Jumean, M., Murad, M. H., Okorodudu, D., Kumar, S., Somers, V. K., Sochor, O., & Lopez-Jimenez, F. (2014). Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis. *Pediatr Obes*, *10*(3), 234-244. https://doi.org/10.1111/ijpo.242

Johansen, M. A., Mikalsen, H. K., & Lagestad, P. A. (2023). Schooltime's contribution to pupils' physical activity levels: A longitudinal study. *Front Public Health*, *11*, 1100984. https://doi.org/10.3389/fpubh.2023.1100984

Jones, M., Defever, E., Letsinger, A., Steele, J., & Mackintosh, K. A. (2020). A mixed-studies systematic review and meta-analysis of school-based interventions to promote physical activity and/or reduce sedentary time in children. *J Sport Health Sci*, *9*(1), 3-17. https://doi.org/10.1016/j.jshs.2019.06.009

Joshi, S. M., Katre, P. A., Kumaran, K., Joglekar, C., Osmond, C., Bhat, D. S., Lubree, H., Pandit, A., Yajnik, C. S., & Fall, C. H. D. (2014). Tracking of cardiovascular risk factors from childhood to young adulthood — the Pune Children's Study. *International Journal of Cardiology*, *175*(1), 176-178. https://doi.org/https://doi.org/10.1016/j.ijcard.2014.04.105

Joubert, N., Walter, C., Du Randt, R., Aerts, A., Adams, L., Degen, J., Gall, S., Müller, I., Nienaber, M., Nqweniso, S., Des Rosiers, S., Seelig, H., Smith, D., Steinmann, P., Probst-Hensch, N., Utzinger, J., Pühse, U., & Gerber, M. (2021). Hypertension among South African children in disadvantaged areas and associations with physical activity, fitness, and cardiovascular risk markers: A cross-sectional study. *Journal of Sports Sciences*, 1-14. https://doi.org/10.1080/02640414.2021.1939964

Juma, K., Juma, P. A. S., Constance Otieno, Peter , & Asiki, G. (2020). Non-Communicable Diseases and Urbanization in African Cities: A Narrative Review. In *Public Health in Developing Countries*. IntechOpen. https://doi.org/10.5772/intechopen.89507

Jürgens, U., Donaldson, R., Rule, S., & Bähr, J. (2013). Townships in South African cities – Literature review and research perspectives. *Habitat International*, *39*, 256-260. https://doi.org/10.1016/j.habitatint.2012.10.011

Kabudula, C. W., Houle, B., Collinson, M. A., Kahn, K., Gomez-Olive, F. X., Clark, S. J., & Tollman, S. (2017). Progression of the epidemiological transition in a rural South African setting: findings from population surveillance in Agincourt, 1993-2013. *BMC Public Health*, *17*(1), 424. https://doi.org/10.1186/s12889-017-4312-x

Kahts-Kramer, S., & Wood, L. (2023). Professional development for physical education teachers: A participatory approach to identifying learning needs. *South African Journal of Education*, *43*(2), 1-9. https://doi.org/10.15700/saje.v43n2a2213

Kahts-Kramer, S. A., du Randt, R., & Wood, L. (2022). Foundation phase teachers' experiences of physical education in low-resourced schools: Implications for continuing professional development *South African Journal for Research in Sport, Physical Education and Recreation*, *44*(2), 29-52. https://doi.org/https://doi.org/10.36386/sajrsper.v44i2.207

Kelsey, M. M., Severn, C., Hilkin, A. M., Pyle, L., Nadeau, K. J., & Zeitler, P. S. (2021). Puberty Is Associated with a Rising Hemoglobin A1c, Even in Youth with Normal Weight. *J Pediatr*, *230*, 244-247. https://doi.org/10.1016/j.jpeds.2020.10.044

Kennedy, S. G., Sanders, T., Estabrooks, P. A., Smith, J. J., Lonsdale, C., Foster, C., & Lubans, D. R. (2021). Implementation at-scale of school-based physical activity interventions: A systematic review utilizing the RE-AIM framework. *Obes Rev*, *22*(7), e13184. https://doi.org/10.1111/obr.13184

Kinsman, J., Norris, S. A., Kahn, K., Twine, R., Riggle, K., Edin, K., Mathebula, J., Ngobeni, S., Monareng, N., & Micklesfield, L. K. (2015). A model for promoting physical activity among rural South African adolescent girls. *Glob Health Action*, *8*, 28790. https://doi.org/10.3402/gha.v8.28790

Klingberg, S., Draper, C. E., Micklesfield, L. K., Benjamin-Neelon, S. E., & van Sluijs, E. M. F. (2019). Childhood Obesity Prevention in Africa: A Systematic Review of Intervention Effectiveness and Implementation. *Int J Environ Res Public Health*, *16*(7). https://doi.org/10.3390/ijerph16071212

Kohl, H. W., 3rd, Craig, C. L., Lambert, E. V., Inoue, S., Alkandari, J. R., Leetongin, G., Kahlmeier, S., & Lancet Physical Activity Series Working, G. (2012). The pandemic of physical inactivity: global action for public health. *Lancet*, *380*(9838), 294-305. https://doi.org/10.1016/S0140-6736(12)60898-8

Kriemler, S., Zahner, L., Schindler, C., Meyer, U., Hartmann, T., Hebestreit, H., Brunner-La Rocca, H. P., van Mechelen, W., & Puder, J. J. (2010). Effect of school based physical activity programme (KISS) on fitness and adiposity in primary schoolchildren: cluster randomised controlled trial. *BMJ (Clinical research ed.)*, *340*(feb23 1), c785-c785. https://doi.org/10.1136/bmj.c785

Kristiansen, F., Mikalsen, H., & Lagestad, P. (2021). School-time's contribution to the physical activity level of children and fulfilment of national health recommendations for physical activity in Norway. *Journal for Research in Arts and Sports Education*, *5*(1), 16-28. https://doi.org/10.23865/jased.v5.2429

Kruger, R., Odili, A., & Gafane-Matemane, L. F. (2023). Editorial: Gaps, priorities, and advances in cardiovascular medicine in Africa. *Frontiers in Cardiovascular Medicine*, *10*. https://doi.org/10.3389/fcvm.2023.1260406

Kyere, P., Veerman, J. L., Lee, P., & Stewart, D. E. (2020). Effectiveness of school-based nutrition interventions in sub-Saharan Africa: a systematic review. *Public Health Nutr*, *23*(14), 2626-2636. https://doi.org/10.1017/S1368980020000506

Lai, S. K., Costigan, S. A., Morgan, P. J., Lubans, D. R., Stodden, D. F., Salmon, J., & Barnett, L. M. (2014). Do school-based interventions focusing on physical activity, fitness, or fundamental movement skill competency produce a sustained impact in these outcomes in children and adolescents? A systematic review of follow-up studies. *Sports Med*, *44*(1), 67-79. https://doi.org/10.1007/s40279-013-0099-9

Lambert, E. V., Kolbe-Alexander, T., Adlakha, D., Oyeyemi, A., Anokye, N. K., Goenka, S., Mogrovejo, P., & Salvo, D. (2020). Making the case for 'physical activity security': the 2020 WHO guidelines on physical activity and sedentary behaviour from a Global South perspective. *Br J Sports Med*, *54*(24), 1447-1448. https://doi.org/10.1136/bjsports-2020-103524

Lambrinou, C. P., Androutsos, O., Karaglani, E., Cardon, G., Huys, N., Wikstrom, K., Kivela, J., Ko, W., Karuranga, E., Tsochev, K., Iotova, V., Dimova, R., De Miguel-Etayo, P., E, M. G.-G., Tamas, H., Jancso, Z., Liatis, S., Makrilakis, K., Manios, Y., . . . Feel4Diabetes-study, g. (2020). Effective strategies for childhood obesity prevention via school based, family involved interventions: a critical review for the development of the Feel4Diabetes-study school based component. *BMC Endocr Disord*, *20*(Suppl 2), 52. https://doi.org/10.1186/s12902-020-0526-5

Lewis, Z. H., Ottenbacher, K. J., Fisher, S. R., Jennings, K., Brown, A. F., Swartz, M. C., Martinez, E., & Lyons, E. J. (2017). The feasibility and RE-AIM evaluation of the TAME health pilot study. *Int J Behav Nutr Phys Act*, *14*(1), 106. https://doi.org/10.1186/s12966-017-0560-5

Li, Y., Ma, Y., Luo, J., Jing, J., Zhang, X., Luo, C., Wang, H., Zhao, H., Pan, D., & Luo, M. (2021). Identifying reference values for serum lipids in Chinese children and adolescents aged 6-17 years old: A national multicenter study. *J Clin Lipidol*, *15*(3), 477-487. https://doi.org/10.1016/j.jacl.2021.02.001

Lobstein, T. (2017). Commentary: which child obesity definitions predict health risk? *Ital J Pediatr*, *43*(1), 20. https://doi.org/10.1186/s13052-017-0337-0

Long, K. Z., Beckmann, J., Lang, C., Seelig, H., Nqweniso, S., Probst-Hensch, N., Muller, I., Puhse, U., Steinmann, P., du Randt, R., Walter, C., Utzinger, J., & Gerber, M. (2022). Impact of a school-based health intervention program on body composition among South

African primary schoolchildren: results from the KaziAfya cluster-randomized controlled trial. *BMC Med*, *20*(1), 27. https://doi.org/10.1186/s12916-021-02223-x

Long, M. W., Sobol, A. M., Cradock, A. L., Subramanian, S. V., Blendon, R. J., & Gortmaker, S. L. (2013). School-day and overall physical activity among youth. *Am J Prev Med*, *45*(2), 150-157. https://doi.org/10.1016/j.amepre.2013.03.011

Lonsdale, C., Rosenkranz, R. R., Peralta, L. R., Bennie, A., Fahey, P., & Lubans, D. R. (2013). A systematic review and meta-analysis of interventions designed to increase moderate-to-vigorous physical activity in school physical education lessons. *Prev Med*, *56*(2), 152-161. https://doi.org/10.1016/j.ypmed.2012.12.004

Love, R., Adams, J., & van Sluijs, E. M. F. (2019). Are school-based physical activity interventions effective and equitable? A meta-analysis of cluster randomized controlled trials with accelerometer-assessed activity. *Obes Rev*, *20*(6), 859-870. https://doi.org/10.1111/obr.12823

Mabweazara, Z. S., Leach, L. L., Smith, M., Tsolekile, L., & Puoane, T. (2019). Ellisras Longitudinal Study 2017: patterns of physical activity in an urban and rural setting among black South African adults (ELS 23). *Cardiovasc J Afr*, *30*(5), 262-267. https://doi.org/10.5830/CVJA-2019-018

Mahler, D. G., Yonzan, N., & Lakner, C. (2022). The Impact of COVID-19 on Global Inequality and Poverty (Policy Research Working Papers, Issue. *Washington, DC, USA: The World Bank*.

Mannocci, A., D'Egidio, V., Backhaus, I., Federici, A., Sinopoli, A., Ramirez Varela, A., Villari, P., & La Torre, G. (2020). Are There Effective Interventions to Increase Physical Activity in Children and Young People? An Umbrella Review. *Int J Environ Res Public Health*, *17*(10). https://doi.org/10.3390/ijerph17103528

Marasso, D., Lupo, C., Collura, S., Rainoldi, A., & Brustio, P. R. (2021). Subjective versus Objective Measure of Physical Activity: A Systematic Review and Meta-Analysis of the Convergent Validity of the Physical Activity Questionnaire for Children (PAQ-C). *Int J Environ Res Public Health*, *18*(7). https://doi.org/10.3390/ijerph18073413

Marques, M. M., Carey, R. N., Norris, E., Evans, F., Finnerty, A. N., Hastings, J., Jenkins, E., Johnston, M., West, R., & Michie, S. (2020). Delivering Behaviour Change Interventions: Development of a Mode of Delivery Ontology. *Wellcome Open Research*, *5*. https://doi.org/10.12688/wellcomeopenres.15906.1

Martinez-Vizcaino, V., Martinez, M. S., Aguilar, F. S., Martinez, S. S., Gutierrez, R. F., Lopez, M. S., Martinez, P. M., & Rodriguez-Artalejo, F. (2010). Validity of a single-factor model underlying the metabolic syndrome in children: a confirmatory factor analysis. *Diabetes Care*, *33*(6), 1370-1372. https://doi.org/10.2337/dc09-2049

Mashili, F. L., Kagaruki, G. B., Mbatia, J., Nanai, A., Saguti, G., Maongezi, S., Magimba, A., Mghamba, J., Kamugisha, M., Mgina, E., Mweya, C. N., Kaushik, R., & Mayige, M. T. (2018). Physical Activity and Associated Socioeconomic Determinants in Rural and Urban Tanzania: Results from the 2012 WHO-STEPS Survey. *International Journal of Population Research*, *2018*, 1-10. https://doi.org/10.1155/2018/4965193

Matsumoto, N., Kubo, T., Nakamura, K., Mitsuhashi, T., Takeuchi, A., Tsukahara, H., & Yorifuji, T. (2021). Trajectory of body mass index and height changes from childhood to adolescence: a nationwide birth cohort in Japan. *Sci Rep*, *11*(1), 23004. https://doi.org/10.1038/s41598-021-02464-z

Mbogori, T., Kimmel, K., Zhang, M., Kandiah, J., & Wang, Y. (2020). Nutrition transition and double burden of malnutrition in Africa: A case study of four selected countries with different social economic development. *AIMS Public Health*, *7*(3), 425-439. https://doi.org/10.3934/publichealth.2020035

McBride, B., Hawkes, S., & Buse, K. (2019). Soft power and global health: the sustainable development goals (SDGs) era health agendas of the G7, G20 and BRICS. *BMC Public Health*, *19*(1), 815. https://doi.org/10.1186/s12889-019-7114-5

McEwan, D., Rhodes, R. E., & Beauchamp, M. R. (2020). What Happens When the Party is Over?: Sustaining Physical Activity Behaviors after Intervention Cessation. *Behav Med*, 1-9. https://doi.org/10.1080/08964289.2020.1750335

McGoey, T., Root, Z., Bruner, M. W., & Law, B. (2015). Evaluation of physical activity interventions in youth via the Reach, Efficacy/Effectiveness, Adoption, Implementation, and Maintenance (RE-AIM) framework: A systematic review of randomised and non-randomised trials. *Prev Med*, *76*, 58-67. https://doi.org/10.1016/j.ypmed.2015.04.006

McKay, H., Naylor, P. J., Lau, E., Gray, S. M., Wolfenden, L., Milat, A., Bauman, A., Race, D., Nettlefold, L., & Sims-Gould, J. (2019). Implementation and scale-up of physical activity and behavioural nutrition interventions: an evaluation roadmap. *Int J Behav Nutr Phys Act*, *16*(1), 102. https://doi.org/10.1186/s12966-019-0868-4

Metcalf, B., Henley, W., & Wilkin, T. (2012). Effectiveness of intervention on physical activity of children: systematic review and meta-analysis of controlled trials with objectively measured outcomes (EarlyBird 54). *BMJ (Clinical research ed.)*, *345*, e5888. https://doi.org/10.1136/bmj.e5888

Meyer, U., Schindler, C., Zahner, L., Ernst, D., Hebestreit, H., van Mechelen, W., Brunner-La Rocca, H. P., Probst-Hensch, N., Puder, J. J., & Kriemler, S. (2014). Long-term effect of a school-based physical activity program (KISS) on fitness and adiposity in children: a cluster-randomized controlled trial. *PLoS One*, *9*(2), e87929. https://doi.org/10.1371/journal.pone.0087929

Miatke, A., Maher, C., Fraysse, F., Dumuid, D., & Olds, T. (2021). Are all MVPA minutes equal? Associations between MVPA characteristics, independent of duration, and childhood adiposity. *BMC Public Health*, *21*(1), 1321. https://doi.org/10.1186/s12889-021-11420-5

Michael, S. L., Merlo, C. L., Basch, C. E., Wentzel, K. R., & Wechsler, H. (2015). Critical connections: health and academics. *J Sch Health*, *85*(11), 740-758. https://doi.org/10.1111/josh.12309

Miller, V., Yusuf, S., Chow, C. K., Dehghan, M., Corsi, D. J., Lock, K., Popkin, B., Rangarajan, S., Khatib, R., Lear, S. A., Mony, P., Kaur, M., Mohan, V., Vijayakumar, K., Gupta, R., Kruger, A., Tsolekile, L., Mohammadifard, N., Rahman, O., . . . Mente, A. (2016).

Availability, affordability, and consumption of fruits and vegetables in 18 countries across income levels: findings from the Prospective Urban Rural Epidemiology (PURE) study. *Lancet Glob Health*, *4*(10), e695-703. https://doi.org/10.1016/S2214-109X(16)30186-3

Milton, K., Cavill, N., Chalkley, A., Foster, C., Gomersall, S., Hagstromer, M., Kelly, P., Kolbe-Alexander, T., Mair, J., McLaughlin, M., Nobles, J., Reece, L., Shilton, T., Smith, B. J., & Schipperijn, J. (2021). Eight Investments That Work for Physical Activity. *J Phys Act Health*, *18*(6), 625-630. https://doi.org/10.1123/jpah.2021-0112

Minja, N. W., Nakagaayi, D., Aliku, T., Zhang, W., Ssinabulya, I., Nabaale, J., Amutuhaire, W., de Loizaga, S. R., Ndagire, E., Rwebembera, J., Okello, E., & Kayima, J. (2022). Cardiovascular diseases in Africa in the twenty-first century: Gaps and priorities going forward. *Front Cardiovasc Med*, *9*, 1008335. https://doi.org/10.3389/fcvm.2022.1008335

Miranda, J. J., Barrientos-Gutierrez, T., Corvalan, C., Hyder, A. A., Lazo-Porras, M., Oni, T., & Wells, J. C. K. (2019). Understanding the rise of cardiometabolic diseases in low- and middle-income countries. *Nat Med*, *25*(11), 1667-1679. https://doi.org/10.1038/s41591-019-0644-7

Moholdt, T., Lavie, C. J., & Nauman, J. (2018). Sustained Physical Activity, Not Weight Loss, Associated With Improved Survival in Coronary Heart Disease. *J Am Coll Cardiol*, *71*(10), 1094-1101. https://doi.org/10.1016/j.jacc.2018.01.011

Moir, T. (2018). Why Is Implementation Science Important for Intervention Design and Evaluation Within Educational Settings? *Frontiers in Education*, *3*. https://doi.org/10.3389/feduc.2018.00061

Monyeki, M. A., De Ridder, J. H., Du Preez, S. M., Toriola, A. L., & Malan, D. D. J. (2012). The effect of a ten month physical activity intervention programme on body

composition of 9–13 year-old boys. *African Journal for Physical, Health Education, Recreation and Dance (AJPHERD)*, *18*(2), 241-250. https://dspace.nwu.ac.za/bitstream/handle/10394/9262/2012Effectof10months%20ajpherd_v18_n2_a4.pdf;sequence=1

Monyeki, M. A., Moss, S. J., Kemper, H. C. G., & Twisk, J. W. R. (2018). Self-Reported Physical Activity is Not a Valid Method for Measuring Physical Activity in 15-Year-Old South African Boys and Girls. *Children (Basel)*, *5*(6). https://doi.org/10.3390/children5060071

Moselakgom, V. K., & Staden, M. V. (2018). Physical Activity and Risk Factors of Cardio-metabolic Diseases in South African Children. *Asian Journal of Scientific Research*, *11*(4), 498-505. https://doi.org/10.3923/ajsr.2018.498.505

Motseke, M. J. (2005). OBE : implementation problems in the black townships of South Africa. *Interim : Interdisciplinary Journal*, *4*(2), 113-121. https://doi.org/10.10520/AJA1684498X_71

Müller, I., Schindler, C., Adams, L., Endes, K., Gall, S., Gerber, M., Htun, N. S. N., Nqweniso, S., Joubert, N., Probst-Hensch, N., du Randt, R., Seelig, H., Smith, D., Steinmann, P.,

Utzinger, J., Yap, P., Walter, C., & Pühse, U. (2019a). Effect of a Multidimensional Physical Activity Intervention on Body Mass Index, Skinfolds and Fitness in South African Children: Results from a Cluster-Randomised Controlled Trial. *Int J Environ Res Public Health*, *16*(2). https://doi.org/10.3390/ijerph16020232

Müller, I., Smith, D., Adams, L., Aerts, A., Damons, B. P., Degen, J., Gall, S., Gani, Z., Gerber, M., Gresse, A., van Greunen, D., Joubert, N., Marais, T., Nqweniso, S., Probst-Hensch, N., du Randt, R., Seelig, H., Steinmann, P., Utzinger, J., . . . Pühse, U. (2019b). Effects of a School-Based Health Intervention Program in Marginalized Communities of Port Elizabeth, South Africa (the KaziBantu Study): Protocol for a Randomized Controlled Trial. *JMIR Res Protoc*, *8*(7), e14097. https://doi.org/10.2196/14097

Müller, I., Walter, C., Du Randt, R., Aerts, A., Adams, L., Degen, J., Gall, S., Joubert, N., Nqweniso, S., Des Rosiers, S., Smith, D., Seelig, H., Steinmann, P., Wadhwani, C., Probst-Hensch, N., Utzinger, J., Pühse, U., & Gerber, M. (2020). Association between physical activity, cardiorespiratory fitness and clustered cardiovascular risk in South African children from disadvantaged communities: results from a cross-sectional study. *BMJ Open Sport Exerc Med*, *6*(1), e000823. https://doi.org/10.1136/bmjsem-2020-000823

Muthuri, S. K., Onywera, V. O., Tremblay, M. S., Broyles, S. T., Chaput, J. P., Fogelholm, M., Hu, G., Kuriyan, R., Kurpad, A., Lambert, E. V., Maher, C., Maia, J., Matsudo, V., Olds, T., Sarmiento, O. L., Standage, M., Tudor-Locke, C., Zhao, P., Church, T. S., . . . Group, I. R. (2016). Relationships between Parental Education and Overweight with Childhood Overweight and Physical Activity in 9-11 Year Old Children: Results from a 12-Country Study. *PLoS One*, *11*(8), e0147746. https://doi.org/10.1371/journal.pone.0147746

Muthuri, S. K., Wachira, L. J., Leblanc, A. G., Francis, C. E., Sampson, M., Onywera, V. O., & Tremblay, M. S. (2014). Temporal trends and correlates of physical activity, sedentary behaviour, and physical fitness among school-aged children in Sub-Saharan Africa: a systematic review. *Int J Environ Res Public Health*, *11*(3), 3327-3359. https://doi.org/10.3390/ijerph110303327

Naidoo, R., Christie, C. J., Lambert, E. V., Nyawose, Z., Monyeki, A., Rensburg, C. J. v., Cozett, C., Naidoo, N., Gradidge, P., & Bassett, S. (2022). Healthy Active Kids South Africa 2022 Report Card. https://www.activehealthykids.org/wp-content/uploads/2023/03/South-Africa-report-card-long-form-2022.pdf

Naidoo, R., & Coopoo, Y. (2012). The impact of a primary school physical activity intervention in KwaZulu-Natal, South Africa. *African Journal for Physical Activity and Health Sciences*, *18*(1). https://www.ajol.info/index.php/ajpherd/article/view/76609

Nally, S., Carlin, A., Blackburn, N. E., Baird, J. S., Salmon, J., Murphy, M. H., & Gallagher, A. M. (2021). The Effectiveness of School-Based Interventions on Obesity-Related Behaviours in Primary School Children: A Systematic Review and Meta-Analysis of Randomised Controlled Trials. *Children (Basel)*, *8*(6). https://doi.org/10.3390/children8060489

National Department of Health. (2013). *Strategic Plan for the Prevention and Control of Non-Communicable Diseases 2013-17*. Retrieved from https://faolex.fao.org/docs/pdf/saf205669.pdf

Naylor, P. J., & McKay, H. A. (2009). Prevention in the first place: schools a setting for action on physical inactivity. *Br J Sports Med*, *43*(1), 10-13. https://doi.org/10.1136/bjsm.2008.053447

Naylor, P. J., Nettlefold, L., Race, D., Hoy, C., Ashe, M. C., Wharf Higgins, J., & McKay, H. A. (2015). Implementation of school based physical activity interventions: a systematic review. *Prev Med*, *72*, 95-115. https://doi.org/10.1016/j.ypmed.2014.12.034

NCD Alliance. (n.d.). The Global Epidemic. *Geneva, Switzerland: NCD Alliance*. Retrieved 05 July 2023 from https://ncdalliance.org/the-global-epidemic

NCD Countdown 2030 collaborators. (2020). NCD Countdown 2030: pathways to achieving Sustainable Development Goal target 3.4. *Lancet*, *396*(10255), 918-934. https://doi.org/10.1016/S0140-6736(20)31761-X

NCD Countdown collaborators. (2018). NCD Countdown 2030: worldwide trends in non-communicable disease mortality and progress towards Sustainable Development Goal target 3.4. *Lancet*, *392*(10152), 1072-1088. https://doi.org/10.1016/S0140-6736(18)31992-5

NCD Risk Factor Collaboration. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*, *390*(10113), 2627-2642. https://doi.org/10.1016/S0140-6736(17)32129-3

Ndinda, C., Ndhlovu, T. P., Juma, P., Asiki, G., & Kyobutungi, C. (2018). The evolution of non-communicable diseases policies in post-apartheid South Africa. *BMC Public Health*, *18*(Suppl 1), 956. https://doi.org/10.1186/s12889-018-5832-8

Ndubuisi, N. E. (2021). Noncommunicable Diseases Prevention In Low- and Middle-Income Countries: An Overview of Health in All Policies (HiAP). *Inquiry*, *58*, 46958020927885. https://doi.org/10.1177/0046958020927885

Neil-Sztramko, S. E., Caldwell, H., & Dobbins, M. (2021). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database Syst Rev*, *9*(9), CD007651. https://doi.org/10.1002/14651858.CD007651.pub3

Neuhauser, H. K., Thamm, M., Ellert, U., Hense, H. W., & Rosario, A. S. (2011). Blood pressure percentiles by age and height from nonoverweight children and adolescents in Germany. *Pediatrics*, *127*(4), e978-988. https://doi.org/10.1542/peds.2010-1290

Nevill, A. M., Duncan, M. J., & Sandercock, G. (2020). Modeling the dose-response rate/associations between VO(2max) and self-reported Physical Activity Questionnaire in children and adolescents. *J Sport Health Sci*, *9*(1), 90-95. https://doi.org/10.1016/j.jshs.2019.05.001

Nguyen, S., Hacker, A. L., Henderson, M., Barnett, T., Mathieu, M. E., Pagani, L., & Bigras, J. L. (2016). Physical Activity Programs with Post-Intervention Follow-Up in Children: A Comprehensive Review According to Categories of Intervention. *Int J Environ Res Public Health*, *13*(7). https://doi.org/10.3390/ijerph13070664

Nielsen, T. R. H., Lausten-Thomsen, U., Fonvig, C. E., Bojsoe, C., Pedersen, L., Bratholm, P. S., Hansen, T., Pedersen, O., & Holm, J. C. (2017). Dyslipidemia and reference values for fasting plasma lipid concentrations in Danish/North-European White children and adolescents. *BMC Pediatr*, *17*(1), 116. https://doi.org/10.1186/s12887-017-0868-y

Nieto-Martinez, R., Gonzalez-Rivas, J. P., & Mechanick, J. I. (2021). Cardiometabolic risk: New chronic care models. *JPEN J Parenter Enteral Nutr*, *45*(S2), 85-92. https://doi.org/10.1002/jpen.2264

Nigg, C. R., Chard, C., Zhang, G., Nigg, C. (2022). Children's physical activity and sedentary behavior is related between different parts of a day. *Current Issues in Sport Science (CISS)*, *7*. https://doi.org/10.36950/2022ciss002

Nilsen, P. (2015). Making sense of implementation theories, models and frameworks. *Implement Sci*, *10*, 53. https://doi.org/10.1186/s13012-015-0242-0

Noubiap, J. J., Essouma, M., Bigna, J. J., Jingi, A. M., Aminde, L. N., & Nansseu, J. R. (2017). Prevalence of elevated blood pressure in children and adolescents in Africa: a systematic review and meta-analysis. *The Lancet Public Health*, *2*(8), e375-e386. https://doi.org/10.1016/s2468-2667(17)30123-8

Nqweniso, S., du Randt, R., Adams, L., Degen, J., Gall, S., Gerber, M., Joubert, N., Müller, I., Smith, D., Seelig, H., Steinmann, P., Probst-Hensch, N., Utzinger, J., Pühse, U., & Walter, C. (2021a). Effect of school-based interventions on body composition of grade-4 children from lower socioeconomic communities in Gqeberha, South Africa. *South African Journal of Child Health*, *15*, 89-98. http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1999-76712021000200006&nrm=iso

Nqweniso, S., Walter, C., du Randt, R., Adams, L., Beckmann, J., Degen, J., Gall, S., Joubert, N., Lang, C., Long, K. Z., Müller, I., Nienaber, M., Pühse, U., Seelig, H., Smith, D., Steinmann, P., Utzinger, J., & Gerber, M. (2021b). Physical Activity, Cardiorespiratory Fitness and Clustered Cardiovascular Risk in South African Primary Schoolchildren from Disadvantaged Communities: A Cross-Sectional Study. *International Journal of Environmental Research and Public Health*, *18*(4). https://doi.org/10.3390/ijerph18042080

Nqweniso, S., Walter, C., du Randt, R., Aerts, A., Adams, L., Degen, J., Gall, S., Gani, Z., Joubert, N., Müller, I., Smith, D., Seelig, H., Steinmann, P., Probst-Hensch, N., Utzinger, J., Pühse, U., & Gerber, M. (2020). Prevention of Overweight and Hypertension through Cardiorespiratory Fitness and Extracurricular Sport Participation among South African Schoolchildren. *Sustainability*, *12*(16). https://doi.org/10.3390/su12166581

Nyangasa, M. A., Buck, C., Kelm, S., Sheikh, M. A., Brackmann, K. L., & Hebestreit, A. (2019). Association between cardiometabolic risk factors and body mass index, waist

circumferences and body fat in a Zanzibari cross-sectional study. *BMJ Open*, *9*(7), e025397. https://doi.org/10.1136/bmjopen-2018-025397

Nyawose, S. E., & Naidoo, R. (2016). The impact of a school-based and family physical activityintervention on learners' health behaviour. *African Journal for Physical Activity and Health Sciences*, *22*(2:1), 378-393.

Okely, A. D., Kariippanon, K. E., Guan, H., Taylor, E. K., Suesse, T., Cross, P. L., Chong, K. H., Suherman, A., Turab, A., Staiano, A. E., Ha, A. S., El Hamdouchi, A., Baig, A., Poh, B. K., Del Pozo-Cruz, B., Chan, C. H. S., Nystrom, C. D., Koh, D., Webster, E. K., . . . Draper, C. E. (2021). Global effect of COVID-19 pandemic on physical activity, sedentary behaviour and sleep among 3- to 5-year-old children: a longitudinal study of 14 countries. *BMC Public Health*, *21*(1), 940. https://doi.org/10.1186/s12889-021-10852-3

Omran, A. R. (1971). The epidemiologic transition. A theory of the epidemiology of population change *Milbank Mem Fund Q.*, *49*(4), 509-538.

Ooi, J. Y., Wolfenden, L., Sutherland, R., Nathan, N., Oldmeadow, C., McLaughlin, M., Barnes, C., Hall, A., Vanderlee, L., & Yoong, S. L. (2022). A Systematic Review of the Recent Consumption Levels of Sugar-Sweetened Beverages in Children and Adolescents From the World Health Organization Regions With High Dietary-Related Burden of Disease. *Asia Pac J Public Health*, *34*(1), 11-24. https://doi.org/10.1177/10105395211014642

Owen, M. B., Curry, W. B., Kerner, C., Newson, L., & Fairclough, S. J. (2017). The effectiveness of school-based physical activity interventions for adolescent girls: A systematic review and meta-analysis. *Preventive Medicine*, *105*, 237-249. https://doi.org/10.1016/j.ypmed.2017.09.018

Oyeyemi, A. L., Ishaku, C. M., Oyekola, J., Wakawa, H. D., Lawan, A., Yakubu, S., & Oyeyemi, A. Y. (2016). Patterns and Associated Factors of Physical Activity among Adolescents in Nigeria. *PLoS One*, *11*(2), e0150142. https://doi.org/10.1371/journal.pone.0150142

Oyeyemi, A. L., Kolbe-Alexander, T. L., & Lambert, E. V. (2021). Case study from Africa. In *Physical Activity in Low- and Middle-Income Countries* (pp. 171-186). https://doi.org/10.4324/9780429344732-10

Pedisic, Z., & Bauman, A. (2015). Accelerometer-based measures in physical activity surveillance: current practices and issues. *Br J Sports Med*, *49*(4), 219-223. https://doi.org/10.1136/bjsports-2013-093407

Peltzer, K., Shisana, O., Zuma, K., Van Wyk, B., & Zungu-Dirwayi, N. (2009). Job stress, job satisfaction and stress-related illnesses among South African educators. *Stress and Health*, *25*(3), 247-257. https://doi.org/10.1002/smi.1244

Pfledderer, C. D., Burns, R. D., Byun, W., Carson, R. L., Welk, G. J., & Brusseau, T. A. (2021). School-based physical activity interventions in rural and urban/suburban communities: A systematic review and meta-analysis. *Obesity Reviews*, *n/a*(n/a), e13265. https://doi.org/https://doi.org/10.1111/obr.13265

Pillay-van Wyk, V., Msemburi, W., Laubscher, R., Dorrington, R. E., Groenewald, P., Glass, T., Nojilana, B., Joubert, J. D., Matzopoulos, R., Prinsloo, M., Nannan, N., Gwebushe, N., Vos, T., Somdyala, N., Sithole, N., Neethling, I., Nicol, E., Rossouw, A., & Bradshaw, D. (2016). Mortality trends and differentials in South Africa from 1997 to 2012: second National Burden of Disease Study. *Lancet Glob Health*, *4*(9), e642-653. https://doi.org/10.1016/S2214-109X(16)30113-9

Poitras, V. J., Gray, C. E., Borghese, M. M., Carson, V., Chaput, J. P., Janssen, I., Katzmarzyk, P. T., Pate, R. R., Connor Gorber, S., Kho, M. E., Sampson, M., & Tremblay, M. S. (2016). Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth. *Appl Physiol Nutr Metab*, *41*(6 Suppl 3), S197-239. https://doi.org/10.1139/apnm-2015-0663

Popova, A., Evans, D. K., Breeding, M. E., & Arancibia, V. (2022). Teacher Professional Development around the World: The Gap between Evidence and Practice. *The World Bank Research Observer*, *37*(1), 107-136. https://doi.org/10.1093/wbro/lkab006

Pratt, M., Ramirez Varela, A. S., Deborah , Kohl III, H. W., & Ding, D. (2020). Attacking the pandemic of physical inactivity: what is holding us back? *Br J Sports Med*, *54*(13), 759–762. https://doi.org/10.1136/bjsports-2019-101392

Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. *Obes Rev*, *2*(3), 141-147. https://doi.org/10.1046/j.1467-789x.2001.00031.x

Prince, S. A., Adamo, K. B., Hamel, M. E., Hardt, J., Connor Gorber, S., & Tremblay, M. (2008). A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. *Int J Behav Nutr Phys Act*, *5*, 56. https://doi.org/10.1186/1479-5868-5-56

Proctor, E., Silmere, H., Raghavan, R., Hovmand, P., Aarons, G., Bunger, A., Griffey, R., & Hensley, M. (2011). Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Adm Policy Ment Health*, *38*(2), 65-76. https://doi.org/10.1007/s10488-010-0319-7

Proctor, E. K., Powell, B.J., McMillen, J.C. (2013). Implementation strategies: recommendations for specifying and reporting. *Implementation Science*, *8*(139). https://doi.org/https://doi.org/10.1186/1748-5908-8-139

Puoane, T., Tsolekile L Fau - Steyn, N., & Steyn, N. (2010). Perceptions about body image and sizes among Black African girls living in Cape Town. (1049-510X (Print)).

Ramires, V. V., Dos Santos, P. C., Barbosa Filho, V. C., Bandeira, A. D. S., Marinho Tenorio, M. C., de Camargo, E. M., Ravagnani, F. C. P., Sandreschi, P., de Oliveira, V. J. M., Hallal, P. C., & Silva, K. S. (2023). Physical Education for Health Among School-Aged Children and Adolescents: A Scoping Review of Reviews. *J Phys Act Health*, *20*(7), 586-599. https://doi.org/10.1123/jpah.2022-0395

Ramirez Varela, A., Hallal, P. C., Mejia Grueso, J., Pedisic, Z., Salvo, D., Nguyen, A., Klepac, B., Bauman, A., Siefken, K., Hinckson, E., Oyeyemi, A. L., Richards, J., Salih Khidir, E. D., Inoue, S., Amagasa, S., Jauregui, A., da Silva, M. C., Lee, I. M., Ding, M., . . . Pratt, M. (2022). Status and Trends of Physical Activity Surveillance, Policy, and Research in

164 Countries: Findings From the Global Observatory for Physical Activity-GoPA! 2015 and 2020 Surveys. *J Phys Act Health*, 1-17. https://doi.org/10.1123/jpah.2022-0464

Ramrathan, L. (2021). School curriculum in South Africa in the Covid-19 context: An opportunity for education for relevance. *Prospects (Paris)*, *51*(1-3), 383-392. https://doi.org/10.1007/s11125-020-09490-1

Reisinger, C., Nkeh-Chungag, B. N., Fredriksen, P. M., & Goswami, N. (2021). The prevalence of pediatric metabolic syndrome-a critical look on the discrepancies between definitions and its clinical importance. *Int J Obes (Lond)*, *45*(1), 12-24. https://doi.org/10.1038/s41366-020-00713-1

Roman-Vinas, B., Chaput, J. P., Katzmarzyk, P. T., Fogelholm, M., Lambert, E. V., Maher, C., Maia, J., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tudor-Locke, C., Tremblay, M. S., & Group, I. R. (2016). Proportion of children meeting recommendations for 24-hour movement guidelines and associations with adiposity in a 12-country study. *Int J Behav Nutr Phys Act*, *13*(1), 123. https://doi.org/10.1186/s12966-016-0449-8

Rossi, L., Behme, N., & Breuer, C. (2021). Physical Activity of Children and Adolescents during the COVID-19 Pandemic-A Scoping Review. *Int J Environ Res Public Health*, *18*(21). https://doi.org/10.3390/ijerph182111440

Salam, R. A., Padhani, Z. A., Das, J. K., Shaikh, A. Y., Hoodbhoy, Z., Jeelani, S. M., Lassi, Z. S., & Bhutta, Z. A. (2020). Effects of Lifestyle Modification Interventions to Prevent and Manage Child and Adolescent Obesity: A Systematic Review and Meta-Analysis. *Nutrients*, *12*(8). https://doi.org/10.3390/nu12082208

Salvini, M., Gall, S., Müller, I., Walter, C., du Randt, R., Steinmann, P., Utzinger, J., Pühse, U., & Gerber, M. (2018). Physical activity and health-related quality of life among schoolchildren from disadvantaged neighbourhoods in Port Elizabeth, South Africa. *Qual Life Res*, *27*(1), 205-216. https://doi.org/10.1007/s11136-017-1707-1

Santos, F., Sousa, H., Gouveia, E. R., Lopes, H., Peralta, M., Martins, J., Murawska-Cialowicz, E., Zurek, G., & Marques, A. (2023). School-Based Family-Oriented Health Interventions to Promote Physical Activity in Children and Adolescents: A Systematic Review. *Am J Health Promot*, *37*(2), 243-262. https://doi.org/10.1177/08901171221113836

Santosa, A., & Byass, P. (2016). Diverse Empirical Evidence on Epidemiological Transition in Low- and Middle-Income Countries: Population-Based Findings from INDEPTH Network Data. *PLoS One*, *11*(5), e0155753. https://doi.org/10.1371/journal.pone.0155753

Schulze, C., Demetriou, Y., Emmerling, S., Schlund, A., Phillips, S. P., Puil, L., Coen, S. E., & Reimers, A. K. (2020). A sex/gender perspective on interventions to promote children's and adolescents' overall physical activity: results from genEffects systematic review. *BMC Pediatr*, *20*(1), 473. https://doi.org/10.1186/s12887-020-02370-9

Sedumedi, C. M., Janssen, X., Reilly, J. J., Kruger, H. S., & Monyeki, M. A. (2021). Association between Objectively Determined Physical Activity Levels and Body Composition in 6–8-

Year-Old Children from a Black South African Population: BC–IT Study. *International Journal of Environmental Research and Public Health*, *18*(12). https://doi.org/10.3390/ijerph18126453

Shelton, R. C., Cooper, B. R., & Stirman, S. W. (2018). The Sustainability of Evidence-Based Interventions and Practices in Public Health and Health Care. *Annu Rev Public Health*, *39*, 55-76. https://doi.org/10.1146/annurev-publhealth-040617-014731

Shisana, O., Labadarios, D., Rehle, T., Simbayin, L., Zuma, K., Dhansay, A., Reddy, P., Parker, W., Hoosain, E., Naidoo, P., Hongoro, C., Mchiza, Z., Steyn, N., Dwane, N., Makoae, M., Maluleke, T., Ramlagan, S., Zungu, N., Evans, M., . . . Team, S.-. (2013). South African National Health and Nutrition Examination Survey (SANHANES-1). Cape Town HSRC Press.

Shoesmith, A., Hall, A., Wolfenden, L., Shelton, R. C., Powell, B. J., Brown, H., McCrabb, S., Sutherland, R., Yoong, S., Lane, C., Booth, D., & Nathan, N. (2021). Barriers and facilitators influencing the sustainment of health behaviour interventions in schools and childcare services: a systematic review. *Implement Sci*, *16*(1), 62. https://doi.org/10.1186/s13012-021-01134-y

Silva, D. A. S., Chaput, J. P., Katzmarzyk, P. T., Fogelholm, M., Hu, G., Maher, C., Olds, T., Onywera, V., Sarmiento, O. L., Standage, M., Tudor-Locke, C., & Tremblay, M. S. (2018). Physical Education Classes, Physical Activity, and Sedentary Behavior in Children. *Med Sci Sports Exerc*, *50*(5), 995-1004. https://doi.org/10.1249/MSS.0000000000001524

Skender, S., Ose, J., Chang-Claude, J., Paskow, M., Bruhmann, B., Siegel, E. M., Steindorf, K., & Ulrich, C. M. (2016). Accelerometry and physical activity questionnaires - a systematic review. *BMC Public Health*, *16*, 515. https://doi.org/10.1186/s12889-016-3172-0

Skinner, A. C., Steiner, M. J., Chung, A. E., & Perrin, E. M. (2012). Cholesterol curves to identify population norms by age and sex in healthy weight children. *Clin Pediatr (Phila)*, *51*(3), 233-237. https://doi.org/10.1177/0009922811430344

Skivington, K., Matthews, L., Simpson, S. A., Craig, P., Baird, J., Blazeby, J. M., Boyd, K. A., Craig, N., French, D. P., McIntosh, E., Petticrew, M., Rycroft-Malone, J., White, M., & Moore, L. (2021). A new framework for developing and evaluating complex interventions: update of Medical Research Council guidance. *BMJ (Clinical research ed.)*, *374*, n2061. https://doi.org/10.1136/bmj.n2061

Smith, D., Adams, L., Du Randt, R., Degen, J., Gall, S., Joubert, N., Müller, I., Nqweniso, S., Pühse, U., Steinmann, P., Utzinger, J., Walter, C., & Gerber, M. (2020). Physical fitness and nutritional anthropometric status of children from disadvantaged communities in the Nelson Mandela Bay region. *South African Journal of Sports Medicine*, *32*(1), 1-8. https://doi.org/10.17159/2078-516X/2020/v32i1a8158

Song, P., Zhang, Y., Yu, J., Zha, M., Zhu, Y., Rahimi, K., & Rudan, I. (2019). Global Prevalence of Hypertension in Children: A Systematic Review and Meta-analysis. *JAMA Pediatr*, 1-10. https://doi.org/10.1001/jamapediatrics.2019.3310

Spaull, N., & Van der Berg, S. (2020). Counting the cost: COVID-19 school closures in South Africa and its impact on children. *South African Journal of Childhood Education*, *10*(1). https://doi.org/10.4102/sajce.v10i1.924

Sport England. (2019). Active lives children and young people survey: Attitudes towards sport and physical activity. *London, UK: Sport England*.

Sriram, K., Mulder, H. S., Frank, H. R., Santanam, T. S., Skinner, A. C., Perrin, E. M., Armstrong, S. C., Peterson, E. D., Pencina, M. J., & Wong, C. A. (2021). The Dose-Response Relationship Between Physical Activity and Cardiometabolic Health in Adolescents. *Am J Prev Med*, *60*(1), 95-103. https://doi.org/10.1016/j.amepre.2020.06.027

Statistics South Africa. (2018). Mortality and causes of death in South Africa: Findings from death notification. https://www.statssa.gov.za/publications/P03093/P030932018.pdf

Statistics South Africa. (2021). Children and the poor are most affected since COVID pandemic. Retrieved 26 August 2023 from https://www.statssa.gov.za/?p=14973

Stavnsbo, M., Resaland, G. K., Anderssen, S. A., Steene-Johannessen, J., Domazet, S. L., Skrede, T., Sardinha, L. B., Kriemler, S., Ekelund, U., Andersen, L. B., & Aadland, E. (2018). Reference values for cardiometabolic risk scores in children and adolescents: Suggesting a common standard. *Atherosclerosis*, *278*, 299-306. https://doi.org/10.1016/j.atherosclerosis.2018.10.003

Stroebel, L. C. E. (2020). Opportunities for all? The impact of resources on the implementation of Physical Education in Free State schools. *African Journal for Physical Activity and Health Sciences (AJPHES)*, *26*(sup1_1), 67-81. https://doi.org/doi:10.37597/ajphes.2020.s.5

Stroebel, L. C. E., Hay, J., & Bloemhoff, H. J. (2016). Physical education in South Africa : have we come full circle? *South African Journal for Research in Sport, Physical Education and Recreation*, *38*(3). https://journals.co.za/doi/epdf/10.10520/EJC199881

Stroebel, L. C. E., Hay, J., & Bloemhoff, H. J. (2017). Needs and challenges of foundation phase life skills teachers in delivering physical education: Jack of all trades and master of none? *South African Journal for Research in Sport, Physical Education and Recreation*, *39*(3). https://www.ajol.info/index.php/sajrs/article/view/164396

Tabak, R. G., Khoong, E. C., Chambers, D. A., & Brownson, R. C. (2012). Bridging research and practice: models for dissemination and implementation research. *Am J Prev Med*, *43*(3), 337-350. https://doi.org/10.1016/j.amepre.2012.05.024

Tarp, J., Jespersen, E., Moller, N. C., Klakk, H., Wessner, B., Wedderkopp, N., & Bugge, A. (2018). Long-term follow-up on biological risk factors, adiposity, and cardiorespiratory fitness development in a physical education intervention: a natural experiment (CHAMPS-study DK). *BMC Public Health*, *18*(1), 605. https://doi.org/10.1186/s12889-018-5524-4

Telford, R. M., Telford, R. D., Olive, L. S., Cochrane, T., & Davey, R. (2016). Why Are Girls Less Physically Active than Boys? Findings from the LOOK Longitudinal Study. *PLoS One*, *11*(3), e0150041. https://doi.org/10.1371/journal.pone.0150041

Tremblay, M. S., Aubert, S., Barnes, J. D., Saunders, T. J., Carson, V., Latimer-Cheung, A. E., Chastin, S. F. M., Altenburg, T. M., Chinapaw, M. J. M., & Participants, S. T. C. P. (2017). Sedentary Behavior Research Network (SBRN) - Terminology Consensus Project process and outcome. *Int J Behav Nutr Phys Act*, *14*(1), 75. https://doi.org/10.1186/s12966-017-0525-8

Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., Goldfield, G., & Gorber, S. C. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 98. https://doi.org/10.1186/1479-5868-8-98

Tulchinsky, T. H., Varavikova, E. A., & Cohen, M. J. (2023). Noncommunicable diseases and conditions. In *The New Public Health* (pp. 367-466). https://doi.org/10.1016/b978-0-12-822957-6.00014-4

Uddin, R., Lee, E. Y., Khan, S. R., Tremblay, M. S., & Khan, A. (2020). Clustering of lifestyle risk factors for non-communicable diseases in 304,779 adolescents from 89 countries: A global perspective. *Prev Med*, *131*, 105955. https://doi.org/10.1016/j.ypmed.2019.105955

UNESCO. (2014). World-wide survey of school physical education: final report. *Paris, France: United Nations Educational, Scientific and Cultural Organization*. https://unesdoc.unesco.org/ark:/48223/pf0000229335

United Nations. (2015a). Sustainable Development Goal 3: Ensure healthy lives and promote well-being for all at all ages. *Geneva, Switzerland: United Nations*. Retrieved 18 July 2023 from https://sdgs.un.org/goals/goal3

United Nations. (2015b). Sustainable Development Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. *Geneva, Switzerland: United Nations*. Retrieved 18 July 2023 from https://sdgs.un.org/goals/goal4

United Nations Children's Fund (UNICEF). (2021). Life in Lockdown: Child and adolescent mental health and well-being in the time of COVID-19 (Innocenti Research Report, Issue. *Florence, Italy: UNICEF Office of Research - Innocenti*.

Uys, M., Bassett, S., Draper, C. E., Micklesfield, L., Monyeki, A., de Villiers, A., Lambert, E. V., & Group, H. W. (2016b). Results From South Africa's 2016 Report Card on Physical Activity for Children and Youth. *J Phys Act Health*, *13*(11 Suppl 2), S265-S273. https://doi.org/10.1123/jpah.2016-0409

Uys, M., Draper, C. E., Hendricks, S., de Villiers, A., Fourie, J., Steyn, N. P., & Lambert, E. V. (2016a). Impact of a South African School-based Intervention, HealthKick, on Fitness Correlates. *Am J Health Behav*, *40*(1), 55-66. https://doi.org/10.5993/AJHB.40.1.7

Väistö, J., Eloranta, A.-M., Viitasalo, A., Tompuri, T., Lintu, N., Karjalainen, P., Lampinen, E.-K., Ågren, J., Laaksonen, D. E., Lakka, H.-M., Lindi, V., & Lakka, T. A. (2014). Physical activity and sedentary behaviour in relation to cardiometabolic risk in children:

cross-sectional findings from the Physical Activity and Nutrition in Children (PANIC) Study. *International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 55. https://doi.org/10.1186/1479-5868-11-55

Van Biljon, A., McKune, A. J., DuBose, K. D., Kolanisi, U., & Semple, S. J. (2018). Physical activity levels in urban-based South African learners: A cross-sectional study of 7 348 participants. *South African Medical Journal*, *108*(2). https://doi.org/10.7196/SAMJ.2018.v108i2.12766

Van Hout, R. C. H., Young, M. E. M., Bassett, S. H., & Hooft, T. (2013). Participation in sport and the perceptions of quality of life of high school learners in the Theewaterskloof Municipality, South Africa. *African Journal for Physical, Health Education, Recreation and Dance (AJPHERD)*, *19*(3), 614-624. https://doi.org/https://hdl.handle.net/10520/EJC142297

van Niekerk, L.-L., du Toit, D., & Pienaar, A. E. (2016). The correlation between motor proficiency and physical activity in Senior Phase learners in the Potchefstroom area. *Health SA Gesondheid*, *21*, 348-355. https://doi.org/10.1016/j.hsag.2016.05.001

van Sluijs, E. M. F., Ekelund, U., Crochemore-Silva, I., Guthold, R., Ha, A., Lubans, D., Oyeyemi, A. L., Ding, D., & Katzmarzyk, P. T. (2021). Physical activity behaviours in adolescence: current evidence and opportunities for intervention. *The Lancet*, *398*(10298), 429-442. https://doi.org/10.1016/s0140-6736(21)01259-9

Vermeulen, H., Meyer, F., & Schönfeldt, H. C. (2023). A basic healthy food basket approach to evaluate the affordability of healthy eating in South Africa and Kenya. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1181683

Villa, J. K., Silva, A. R., Santos, T. S., Ribeiro, A. Q., & Sant'Ana, L. F. (2015). Metabolic syndrome risk assessment in children: use of a single score. *Rev Paul Pediatr*, *33*(2), 187-193. https://doi.org/10.1016/j.rpped.2014.11.001 (Risco de sindrome metabolica em criancas: uso de um escore unico.)

Volf, K., Kelly, L., Van Hoye, A., Garcia Bengoechea, E., MacPhail, A., Woods, C. B., & Consortium, P. E. N. (2023). Assessing the implementation of physical activity-promoting public policies in the Republic of Ireland: a study using the Physical Activity Environment Policy Index (PA-EPI). *Health Res Policy Syst*, *21*(1), 63. https://doi.org/10.1186/s12961-023-01013-6

Vosloo, J. J., & du Toit, D. (2023). Sports Participation in South African Schools. Have We Lost the Plot? In W. Lucy-Joy (Ed.), *Sport and Fitness in Children and Adolescents* (pp. Ch. 5). IntechOpen. https://doi.org/10.5772/intechopen.106812

Wachira, L. J., Hayker, S. O., Larouche, R., Oyeyemi, A. L., Prista, A., Owino, G. E., Tremblay, M. S., & Onywera, V. O. (2022). Physical activity and active transportation behaviour among rural, peri-urban and urban children in Kenya, Mozambique and Nigeria: The PAAT Study. *PLoS One*, *17*(1), e0262768. https://doi.org/10.1371/journal.pone.0262768

Walter, C. M. (2011). In-school physical activity patterns of primary school learners from disadvantaged schools in South Africa. *African Journal for Physical, Health Education, Recreation and Dance (AJPHERD)*, *17*(4), 780-789.

Walter, C. M. (2014). Promoting physical activity: A low cost intervention programme for disadvantaged schools in Port Elizabeth, South Africa. *African Journal for Physical Activity and Health Sciences*, *20*(2). https://www.ajol.info/index.php/ajpherd/article/view/105502

Wang, G., Walker, S. O., Hong, X., Bartell, T. R., & Wang, X. (2013). Epigenetics and early life origins of chronic noncommunicable diseases. *J Adolesc Health*, *52*(2 Suppl 2), S14-21. https://doi.org/10.1016/j.jadohealth.2012.04.019

Wang, H., Zhou, Y., Blake, H., & Chattopadhyay, K. (2022). School-Based Physical Activity Intervention: A Qualitative Process Evaluation of a Feasibility Trial in Yangzhou, China. *Int J Environ Res Public Health*, *19*(2). https://doi.org/10.3390/ijerph19021021

Weimann, A., & Oni, T. (2019). A Systematised Review of the Health Impact of Urban Informal Settlements and Implications for Upgrading Interventions in South Africa, a Rapidly Urbanising Middle-Income Country. *Int J Environ Res Public Health*, *16*(19). https://doi.org/10.3390/ijerph16193608

Wellman, R. J., Sylvestre, M. P., Abi Nader, P., Chiolero, A., Mesidor, M., Dugas, E. N., Tougri, G., & O'Loughlin, J. (2020). Intensity and frequency of physical activity and high blood pressure in adolescents: A longitudinal study. *J Clin Hypertens (Greenwich)*, *22*(2), 283-290. https://doi.org/10.1111/jch.13806

Weres, A., Baran, J., Czenczek-Lewandowska, E., Leszczak, J., & Mazur, A. (2022). The association between steps per day and blood pressure in children. *Sci Rep*, *12*(1), 1422. https://doi.org/10.1038/s41598-022-05497-0

Wolfenden, L., McCrabb, S., Barnes, C., O'Brien, K. M., Ng, K. W., Nathan, N. K., Sutherland, R., Hodder, R. K., Tzelepis, F., Nolan, E., Williams, C. M., & Yoong, S. L. (2022). Strategies for enhancing the implementation of school-based policies or practices targeting diet, physical activity, obesity, tobacco or alcohol use. *Cochrane Database Syst Rev*, *8*(8), CD011677. https://doi.org/10.1002/14651858.CD011677.pub3

Wolfenden, L., Reilly, K., Kingsland, M., Grady, A., Williams, C. M., Nathan, N., Sutherland, R., Wiggers, J., Jones, J., Hodder, R., Finch, M., McFadyen, T., Bauman, A., Rissel, C., Milat, A., Swindle, T., & Yoong, S. L. (2019). Identifying opportunities to develop the science of implementation for community-based non-communicable disease prevention: A review of implementation trials. *Prev Med*, *118*, 279-285. https://doi.org/10.1016/j.ypmed.2018.11.014

World Bank. (2020). The Human Capital Index 2020 Update: Human Capital in the Time of COVID-19. *Washington, DC, USA: The World Bank*. https://openknowledge.worldbank.org/server/api/core/bitstreams/8ca3928c-0e04-59bf-ba37-713442d6fab0/content

World Bank. (n.d.). Country profile: South Africa. *Washington, D.C., USA: The World Bank*. Retrieved 07 July 2023 from https://data.worldbank.org/country/south-africa

World Health Organization. (2010). Global recommendations on physical activity for health. *Geneva, Switzerland: World Health Organization*. https://www.who.int/publications/i/item/9789241599979

World Health Organization. (2013). *Global action plan for the prevention and control of NCDs 2013–2020*. Geneva, Switzerland: World Health Organization Retrieved from https://www.who.int/publications/i/item/9789241506236

World Health Organization. (2015). *Guideline: Sugars Intake for Adults and Children*. Geneva, Switzerland: World Health Organization Retrieved from https://www.who.int/publications/i/item/9789241549028

World Health Organization. (2018). Global action plan on physical activity 2018–2030: more active people for a healthier world. *Geneva*. https://www.who.int/publications/i/item/9789241514187

World Health Organization. (2022). Global status report on physical activity 2022. *Geneva, Switzerland: World Health Organization*. https://apps.who.int/iris/rest/bitstreams/1473751/retrieve

World Health Organization. (n.d.-a). Noncommunicable diseases. *Geneva, Switzerland: World Health Organization*. Retrieved 04 July 2023 from https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases

World Health Organization. (n.d.-b). Physical activity. *Geneva, Switzerland: World Health Organization*. Retrieved 09 May 2023 from https://www.who.int/news-room/fact-sheets/detail/physical-activity

Xi, B., Zong, X., Kelishadi, R., Hong, Y. M., Khadilkar, A., Steffen, L. M., Nawarycz, T., Krzywinska-Wiewiorowska, M., Aounallah-Skhiri, H., Bovet, P., Chiolero, A., Pan, H., Litwin, M., Poh, B. K., Sung, R. Y., So, H. K., Schwandt, P., Haas, G. M., Neuhauser, H. K., . . . International Child Blood Pressure References Establishment, C. (2016). Establishing International Blood Pressure References Among Nonoverweight Children and Adolescents Aged 6 to 17 Years. *Circulation*, *133*(4), 398-408. https://doi.org/10.1161/CIRCULATIONAHA.115.017936

Xu, G., Sun, N., Li, L., Qi, W., Li, C., Zhou, M., Chen, Z., & Han, L. (2020). Physical behaviors of 12-15 year-old adolescents in 54 low- and middle-income countries: Results from the Global School-based Student Health Survey. *J Glob Health*, *10*(1), 010423. https://doi.org/10.7189/jogh.10.010423

Yap, P., Müller, I., Walter, C., Seelig, H., Gerber, M., Steinmann, P., Damons, B. P., Smith, D., Gall, S., Banninger, D., Hager, T., Htun, N. S., Steenkamp, L., Gresse, A., Probst-Hensch, N., Utzinger, J., Du Randt, R., & Pühse, U. (2015). Disease, activity and schoolchildren's health (DASH) in Port Elizabeth, South Africa: a study protocol. *BMC Public Health*, *15*, 1285. https://doi.org/10.1186/s12889-015-2636-y

Yapa, H. M., & Barnighausen, T. (2018). Implementation science in resource-poor countries and communities. *Implement Sci*, *13*(1), 154. https://doi.org/10.1186/s13012-018-0847-1

Yuksel, H. S., Sahin, F. N., Maksimovic, N., Drid, P., & Bianco, A. (2020). School-Based Intervention Programs for Preventing Obesity and Promoting Physical Activity and Fitness: A Systematic Review. *Int J Environ Res Public Health*, *17*(1). https://doi.org/10.3390/ijerph17010347

Zar, H. J., Dawa, J., Fischer, G. B., & Castro-Rodriguez, J. A. (2020). Challenges of COVID-19 in children in low- and middle-income countries. *Paediatr Respir Rev*, *35*, 70-74. https://doi.org/10.1016/j.prrv.2020.06.016

Zimu, P. M., Van Heerden, H. J., & Grace, J. M. (2020). Physical activity patterns and levels of adolescent learners from low and middle socio-economic status communities in Kwazulu-Natal Province. *South African Journal for Research in Sport, Physical Education and Recreation*, *42*(1), 105-114. https://doi.org/https://hdl.handle.net/10520/EJC-1d512774cf

Zulu, J. K., Bhengu, T. T., & Mkhize, B. N. (2019). Leadership challenges and responses to complex township school life: perspectives from four secondary schools in South Africa. *International Journal of Leadership in Education*, *24*(2), 206-225. https://doi.org/10.1080/13603124.2019.1623918

Appendix

Contributions to the PhD project

The *KaziBantu* project, of which *KaziKidz* forms part, is a collaboration between researchers from the Department of Sport, Exercise, and Health at the University of Basel in Switzerland, the Department of Human Movement Science at the Nelson Mandela University in South Africa, and the Swiss Tropical and Public Health Institute.

The *KaziBantu* project stemmed from the experiences gained from the prior DASH study, leading to its development and implementation as a RCT in 2019. Towards the conclusion of this trial, the PhD candidate, Patricia Arnaiz, in collaboration with Prof. Uwe Pühse and Dr. Ivan Müller, recognised the critical importance of assessing the upcoming phase of the project, namely the sustainability phase. Consequently, the candidate conducted a comprehensive literature research to identify relevant methods pertaining to the study of the sustainability of public health interventions. Under the leadership of Prof. Uwe Pühse, a research proposal was prepared by the candidate with invaluable support from project partners including Prof. Markus Gerber, Dr. Ivan Müller, and Dr. Harald Seelig from the Department of Sport, Exercise and Health of the University of Basel, Prof. Cheryl Walter, Prof. Rosa du Randt, Prof. Darelle van Greunen, Dr. Bruce Damons, and Ms. Larissa Adams from the Department of Human Movement Science of the Nelson Mandela University, Prof. Max Bergman from the Social Science Department of the University of Basel, and Prof. Jürg Utzinger and P.D. Peter Steinman from the Swiss Tropical and Public Health Institute. Said proposal was submitted to the Swiss National Science Foundation (SNSF) in October 2019 and was granted in March 2020, under grant number 192651. Following acceptance, the candidate secured approval from the Ethics Committee Northwest and Central Switzerland and Prof. Rosa du Randt from the Nelson Mandela University Human Ethics Committee as well as the Eastern Cape Departments of Education and Health Ethics. Thereafter, the candidate, together with Prof. Uwe Pühse and Dr. Ivan Müller, managed the project as regards the funding agency SNSF, overseeing tasks that involved budget management, the submission of financial and scientific reports, and the application for a grant extension.

The PhD candidate joined the research team in South Africa between August and November 2021 to carry out fieldwork. Data collection responsibilities were allocated within the team, with the

candidate organising and conducting qualitative assessments, while quantitative measurements were led by Dr. Danielle Dolley, Dr. Siphesihle Nqweniso, Ms. Larissa Adams, and Ms. Madeleine Nienaber. The entire team collaborated on data cleaning and the candidate compiled the complete datasets for all time points.

Turning to research outputs, the candidate formulated research questions, defined objectives, and selected appropriate methods for all publications with autonomy. She analysed all collected data with support from Dr. Harald Seelig and Prof. Max Bergman and drafted the five PhD-related manuscripts, which were subsequently revised by all co-authors. Two of these manuscripts, Publication 2 and 3, were published with shared first authorship alongside Mr. Felix Guntlisbergen (a Master student supervised by the candidate) and Ms. Larissa Adams, respectively. The candidate handled the submission of all manuscripts to recognised international, peer-reviewed journals. Moreover, the candidate regularly presented research findings at international conferences and internal meetings, supervised Bachelor and Master's theses, and conducted peer reviews.