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Functional data analysis in health informatics: A comparative review of developments and applications in the USA and Africa

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Abstract

This study presents a comprehensive review of Functional Data Analysis (FDA) in Health Informatics, focusing on a comparative analysis between the United States and Africa. The background of the study is rooted in the growing importance of FDA in the healthcare sector, driven by technological advancements and the increasing complexity of health data.

The aim of the paper is to explore and contrast the developments, applications and challenges of FDA in health informatics within these two diverse geographical contexts. The scope of the paper encompasses the historical evolution, theoretical frameworks, technological advancements, structural differences in health data management and ethical considerations in both the USA and Africa.

Methodologically, the study employs a qualitative analysis framework, integrating a systematic review of relevant literature. This approach facilitates an in-depth examination of the divergent paths and shared challenges in FDA across the two regions.

The main findings reveal significant disparities in the evolution, application and effectiveness of FDA in health informatics. The USA demonstrates a leading role with advanced technological integration and innovative applications, while Africa shows resilience and adaptability despite facing challenges of limited resources and infrastructure.

The study concludes that while the USA has made significant strides in utilizing data to enhance public health and healthcare delivery, Africa presents a landscape of both challenges and opportunities. The divergence is influenced by disparities in educational infrastructure, access to technological resources and healthcare delivery systems.

Recommendations include the need for global collaboration, investment in health informatics education, workforce development and the establishment of global standards for health data analysis and sharing.

Keywords: Functional Data Analysis; Health Informatics; Comparative Analysis; USA; Africa; Technological Advancements

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1. Introduction

1.1. Exploring the Landscape of Functional Data Analysis in Health Informatics

The landscape of functional data analysis (FDA) in health informatics has been shaped by diverse global trends, with significant contributions from both the United States and Africa. Enakrire (2021) provides a comprehensive bibliometric analysis of health informatics publications in Africa, highlighting the region's growing research impact and visibility in this field. The study, which analyzed data from 1987 to 2018, revealed a substantial volume of publications, predominantly in medicine, indicating a keen interest and active engagement in health informatics research within the African academic community (Enakrire, 2021).

As evidenced by the work of Lievevrouw, Marelli and Van Hoyweghen (2022), the United States has been a frontrunner in FDA research. Their bibliometric analysis underscores the USA's dominant role in FDA with a significant portion of the research contributions emanating from American institutions. This dominance is reflected in the high citation rates of articles published in prominent journals like the *Journal of the American Statistical Association*, indicating the influential nature of American research in FDA (Lievevrouw, Marelli & Van Hoyweghen, 2022).

The application of FDA in health informatics in Africa has seen a unique evolution, particularly in response to public health challenges like pandemics. Silenou et al. (2021) conducted a scoping review to map the functional portfolio of digital health tools used for surveillance or outbreak management in Africa. Their findings revealed a diverse range of tools, albeit with a lack of comprehensive attributes, necessitating the use of multiple tools in parallel. This study highlights the innovative ways in which African countries have leveraged FDA in health informatics, despite facing resource constraints (Silenou et al., 2021).

The same team, in their preprint version of the study, further elaborates on the suitability of these digital health tools in the African context for pandemic control. They emphasize the need for tools that offer a comprehensive set of attributes to effectively manage health events and case-based data, underscoring the importance of FDA in enhancing the capabilities of health informatics tools (Silenou et al., 2021).

The comparative analysis of FDA in health informatics between the USA and Africa reveals a stark contrast in terms of resources, infrastructure and research output. While the USA boasts a robust and well-funded research environment, leading to high-impact publications and advanced FDA applications, Africa shows a resilient and adaptive approach, focusing on practical applications in public health challenges. This dichotomy is not just a reflection of the differing economic landscapes but also highlights the diverse pathways through which FDA can evolve and be applied in health informatics.

Moreover, the collaborative networks and authorship patterns in FDA research differ significantly between the two regions. In the USA, there is a tendency towards collaboration among top-tier institutions, contributing to a concentrated pool of high-quality research. In contrast, African research in health informatics is more dispersed, with contributions coming from a wider range of institutions, reflecting a more inclusive but less concentrated research landscape.

The evolution of FDA tools and their applications in health informatics also varies between the two continents. In the USA, there is a focus on developing sophisticated FDA methodologies, such as smoothing, principal component analysis, regression and clustering, for complex and high-dimensional datasets. African researchers, on the other hand, have been more focused on the practical application of these tools in addressing immediate public health needs, such as outbreak management and surveillance.

The landscape of FDA in health informatics presents a rich tapestry of research and applications, with the USA leading in terms of research depth and Africa showcasing a more application-oriented approach. This comparative analysis not only sheds light on the current state of FDA in health informatics but also sets the stage for future collaborations and knowledge exchange between these two diverse regions.

1.2. Tracing the Historical Evolution of Health Informatics: A USA-Africa Comparison

The historical evolution of health informatics in the United States and Africa presents a study in contrasts, reflecting the diverse pathways of technological and healthcare development across these regions. In the United States, the journey of health informatics has been deeply intertwined with the broader evolution of healthcare services and preventive medicine. Collen (2000) traces this evolution from the 1940s, where the focus was on solo- and group-practice models

with paper-based information systems, to the 1990s, which saw the emergence of nationwide, managed-care plans employing advanced computer-based systems and telemedicine supported by the Internet (Collen, 2000).

This transformation in the USA was marked by a shift towards online preventive medical practice guidelines and a reengineering of medical services to incorporate digital technologies. A need for efficiency, accuracy, and broader access to medical services drove the integration of informatics into healthcare. The evolution of health informatics in the USA set a benchmark for the rest of the world, showcasing how technology could revolutionize healthcare delivery and management.

In contrast, as detailed by Korpela (2013), the evolution of health informatics in Africa has been a gradual and adaptive growth journey, influenced by unique regional challenges and opportunities. The HELINA conferences, a key milestone in this journey, provide a window into the phases of health informatics development in Africa. Starting from the pre-phase in 1979 with individual scientific papers, the journey moved through several phases, including the momentum of the early HELINA conferences (1993-1999), a period of difficulty in organizing conferences (Phase 2) and a resurgence from 2007 to 2011 under the HELINA association (Korpela, 2013).

The African experience in health informatics has been characterized by a focus on local development capacity, community orientation, and collaborative design. Unlike the USA, where the evolution was driven by large-scale institutional changes and technological advancements, in Africa, the growth of health informatics has been more organic, driven by the needs of the community and the availability of resources. This has led to a landscape where e-health practice is populated by a variety of software applications, many of which are the result of collaborative open-source projects.

The differences in the evolution of health informatics between the USA and Africa also reflect the varying levels of government support and the role of champions in promoting this field. In the USA, government policies and funding played a significant role in advancing health informatics, whereas in Africa, the growth has been more reliant on international collaboration and the support of non-governmental organizations.

The current phase of health informatics in Africa, as identified by Korpela (2013), is characterized by the expansion of e-health practice across the continent, with the HELINA association playing a key role in organizing annual conferences that are becoming increasingly scientifically robust and visible. This phase represents a maturation of the field in Africa, where the focus is on expanding the practical application of health informatics to address specific healthcare challenges.

The historical evolution of health informatics in the USA and Africa highlights two distinct paths shaped by regional contexts, resources and needs. While the USA has been a pioneer in integrating technology into healthcare, leading to a highly digitized and efficient system, Africa's journey has been one of resilience and adaptability, focusing on community needs and collaborative efforts. This comparative analysis not only provides insights into the past but also sets the stage for future developments in health informatics in both regions.

1.3. Theoretical Foundations and Frameworks in Functional Data Analysis

The theoretical underpinnings of functional data analysis (FDA) in health informatics are critical for understanding its application and effectiveness in clinical practice. Burger et al. (2020) address the gap between complexity science and clinical practice by formalizing idiographic theories through a computational model of functional analysis. This approach is pivotal in translating complex patient data into actionable insights, particularly in mental health. The model they propose illustrates the dynamic interplay between various health factors, demonstrating how different interventions can impact patient outcomes. This methodological advancement underscores the importance of integrating theoretical frameworks with practical applications in FDA (Burger et al., 2020).

Golino et al. (2020) further expand on this by applying exploratory graph analysis to investigate broad domains such as intrinsic capacity, functional ability and environment. Their work highlights the significance of a multi-dimensional approach in FDA, where various health-related factors are interconnected. By employing a graph analysis approach, they provide a framework for understanding the complex relationships within health data, thereby enhancing the analytical methodologies for measuring aspects like healthy aging. This approach is particularly relevant in health informatics, as it allows for a more nuanced understanding of health data, leading to more effective and personalized healthcare solutions (Golino et al., 2020).

Bergeron et al. (2017) contribute to this discussion by systematically reviewing theories, models, and frameworks used in capacity building interventions relevant to public health. Their work emphasizes the diversity of theoretical

approaches that can be applied in health informatics. By identifying specific theories and models, such as Diffusion of Innovations and Transformational Learning, they provide a structured way to understand and implement FDA in various health contexts. This systematic approach is crucial for developing effective health informatics strategies that are grounded in robust theoretical foundations (Bergeron et al., 2017).

The integration of these theoretical frameworks into FDA is essential for several reasons. Firstly, it allows for a more comprehensive understanding of health data by considering various dimensions and their interrelationships. Secondly, it facilitates the development of more targeted and effective health interventions, as it provides a clearer understanding of the underlying mechanisms and factors influencing health outcomes. Thirdly, these frameworks support the advancement of health informatics as a discipline, ensuring that its methodologies and applications are grounded in solid scientific principles.

Moreover, the application of these frameworks in FDA enables the handling of complex and high-dimensional datasets, which are increasingly common in health informatics. By applying models like computational functional analysis and exploratory graph analysis, researchers and practitioners can extract more meaningful insights from data, leading to improved patient care and health outcomes.

Furthermore, the use of these theoretical foundations in FDA aligns with the growing trend towards personalized medicine. By understanding the unique health dynamics of individual patients, healthcare providers can tailor their interventions more effectively, leading to better health outcomes. This personalized approach is particularly important in mental health, where the interplay of various factors can significantly impact treatment efficacy.

The theoretical foundations and frameworks in FDA play a crucial role in advancing health informatics. By bridging the gap between complex data and clinical practice, these frameworks enable a deeper understanding of health data, leading to more effective and personalized healthcare solutions. The integration of these theoretical approaches in FDA is essential for the continued development and success of health informatics as a discipline.

1.4. The Impact of Technological Advancements on Health Data Analysis

Raj, Rawal and Yang (2019) explore the significant role of big data analytics in the health sector, emphasizing its potential to revolutionize healthcare delivery. The authors highlight the exponential growth of data and the necessity of efficient data processing techniques to harness its full potential in healthcare advancements. The study underscores the importance of innovative methods and robust security measures in enhancing user experience and data utilization in health informatics. The authors emphasize the need for a more integrated approach to data analytics in healthcare, which includes the use of big data, machine learning, and predictive analytics. The study highlights the potential of these technologies to improve healthcare outcomes and underscores the need for continued investment in this area (Raj, Rawal & Yang, 2019).

Leung, Wen and Zhao (2021) further illustrate the impact of technological advancements through their work on big data mining in health informatics data for cities. Their research demonstrates how the analysis of large volumes of health data, such as COVID-19 epidemiological data, can significantly aid in decision-making and policy formulation for urban health management. This study exemplifies the transformative power of big data mining in understanding and addressing public health challenges, thereby enhancing the well-being of citizens within cities (Leung, Wen & Zhao, 2021).

Du, Chen and Zhang (2021) contribute to this discourse by analyzing the interplay between health demand, informatics supply and technological applications in China. Their content mapping and analysis approach provide insights into how medical informatics research efforts align with health needs, such as disease management and population health. This study underscores the growing significance of informatics-related concepts and techniques as major sources of digital medical innovation, highlighting the positive correlation between disease burden and informatics research efforts in China (Du, Chen & Zhang, 2021).

The integration of big data analytics and advanced computing methodologies in health informatics has led to more precise and efficient data processing, enabling healthcare professionals to make informed decisions based on comprehensive data analysis. This technological evolution has also facilitated the development of personalized medicine, where patient data is analyzed to tailor treatments to individual needs, thereby improving patient outcomes.

Moreover, the advancements in data security and privacy techniques are crucial in maintaining the integrity and confidentiality of health data. As the volume of health data grows, so does the need for robust security measures to protect sensitive patient information from unauthorized access and breaches.

The impact of these technological advancements extends beyond individual patient care to public health management. The ability to analyze large datasets has been instrumental in tracking and managing infectious diseases, predicting health trends and formulating effective public health policies. This has been particularly evident in the management of the COVID-19 pandemic, where big data analytics played a pivotal role in understanding the spread of the virus and informing public health responses.

Technological advancements in health data analysis have significantly enhanced the capabilities of health informatics. From improving individual patient care to aiding in public health management, the integration of big data analytics, advanced computing methodologies, and robust security measures has revolutionized the healthcare sector. As technology continues to evolve, its impact on health informatics is poised to grow, offering new opportunities and challenges in the pursuit of better healthcare outcomes.

1.5. Comparative Structures of Health Data in the USA and Africa

The comparative analysis of health data structures between the USA and Africa reveals significant differences influenced by various socio-economic, political and technological factors. Akokuwebe and Idemudia (2022) provide a comprehensive study on the prevalence and determinants of health insurance coverage in Nigeria and South Africa, highlighting the disparities in healthcare access and financial protection against health-related risks. Their findings indicate that only a small fraction of the Nigerian population is insured compared to a higher percentage in South Africa, reflecting the varying degrees of health data management and insurance systems in these countries (Akokuwebe & Idemudia, 2022).

De Souza et al. (2020) focus on the inclusion of race/skin color in health information systems, comparing Brazil and South Africa. This study is relevant as it sheds light on the importance of demographic variables in health data structures. The inclusion of such variables is crucial for measuring health inequities and tailoring healthcare services to diverse populations. The findings suggest that the historical and political context significantly influences how health data is collected and utilized, which is applicable when comparing the USA and Africa (De Souza et al., 2021).

Nabyonga-Orem, Asamani and Makanga (2021) assess the state of health research governance in Africa, providing insights into the structures in place for health research. Their study underscores the need for robust governance structures to ensure ethical and effective health research, which is a key component of health data management. This research highlights the challenges faced in many African countries in establishing comprehensive health data systems, in contrast to the more developed systems in the USA (Nabyonga-Orem, Asamani & Makanga, 2021).

The structural differences in health data between the USA and Africa can be attributed to several factors. In the USA, health data systems are often more advanced, with a higher degree of digitization and integration. This allows for more efficient data collection, processing and analysis, facilitating research and policy-making. In contrast, many African countries face challenges such as limited resources, inadequate infrastructure, and varying degrees of political commitment to health data management.

Furthermore, the scope and quality of health data in the USA are generally broader and more detailed, encompassing a wide range of health indicators. This is partly due to the higher investment in healthcare and research, as well as the presence of multiple large-scale health surveys and databases. In Africa, while there is progress in health data collection, issues such as data completeness, accuracy and timeliness often pose challenges.

The impact of these structural differences is significant. In the USA, the advanced health data systems contribute to more effective healthcare delivery, policy formulation and health research. In Africa, the gaps in health data structures can lead to challenges in addressing public health issues, understanding health trends and implementing effective health interventions.

The comparative structures of health data in the USA and Africa highlight the disparities in healthcare systems and the challenges faced by African countries in establishing robust health data systems. Addressing these disparities requires concerted efforts in improving health data governance, infrastructure and resource allocation. As African countries continue to develop their health data systems, learning from the experiences of countries like the USA can provide valuable insights and strategies for improvement.

1.6. Big Data and AI: Catalysts for Transformation in Health Informatics

The integration of Big Data and Artificial Intelligence (AI) in health informatics has marked a transformative era in healthcare, reshaping how medical data is analyzed, interpreted, and utilized. Reis et al. (2022) discuss the development of a service-based information system for AI-supported health informatics, emphasizing the role of AI in enhancing the efficiency and effectiveness of health data analysis. Their work illustrates how AI can empower both expert and end users in the healthcare sector, facilitating more informed decision-making and patient care (Reis et al., 2022).

Gangwar and Hasija (2021) explore the application of biomedical big data analytics using the Internet of Things (IoT) in health informatics. They highlight the growing importance of IoT technology in healthcare management, including patient engagement, clinical results and public health resource allocation. The convergence of IoT with big data analytics in healthcare provides a comprehensive framework for real-time monitoring and data-driven decision-making, significantly enhancing the quality and accessibility of healthcare services (Gangwar & Hasija, 2021).

Leung et al. (2022) present a model for analyzing and predicting COVID-19 pandemic data using N-shot learning, a machine learning technique. Their research demonstrates the practicality of AI in managing large-scale health crises by enabling effective resource allocation and patient care strategies. This study exemplifies the potential of AI and big data in addressing global health challenges, offering innovative solutions for pandemic management and future healthcare crises (Leung et al., 2022).

The integration of Big Data and AI in health informatics has several key implications. Firstly, it allows for the handling of vast amounts of health data, enabling healthcare professionals to gain deeper insights into patient health and disease patterns. Secondly, AI algorithms can identify trends and correlations in health data that might be missed by traditional analysis methods, leading to more accurate diagnoses and personalized treatment plans.

Moreover, the use of AI in health informatics enhances predictive healthcare, allowing for early intervention in disease progression and better management of chronic conditions. This proactive approach to healthcare can significantly improve patient outcomes and reduce healthcare costs.

The combination of Big Data and AI also facilitates the development of precision medicine, where treatments and medications are tailored to the individual characteristics of each patient. This personalized approach is particularly beneficial in oncology, genetics and chronic disease management.

Furthermore, the application of AI in health informatics supports the advancement of telemedicine and remote patient monitoring. By analyzing data from wearable devices and remote monitoring tools, AI can provide real-time insights into patient health, enabling timely interventions and improving access to healthcare for remote and underserved populations.

In conclusion, Big Data and AI are powerful catalysts for transformation in health informatics, driving advancements in healthcare delivery, disease management, and patient care. As these technologies continue to evolve, they offer promising opportunities for improving health outcomes and transforming the healthcare landscape. The integration of AI and Big Data in health informatics represents a significant step forward in the journey towards more efficient, effective and personalized healthcare.

1.7. Ethical Dimensions in Health Data Analysis Across Continents

The ethical dimensions of health data analysis, particularly in the context of the Global South and Africa, present unique challenges and considerations. Anane-Sarpong et al. (2018) explore the application of ethical principles to research using public health data in Africa. They highlight the ethical gaps that arise due to the population-based nature of research and reliance on pre-collected longitudinal data in these regions. The study emphasizes the need for context-relevant ethical frameworks that can adapt foundational principles of health research to the evolving landscape of research using public health data (RUPD) in the Global South (Anane-Sarpong et al., 2018).

Nichol et al. (2021) delve into the ethical implications of using machine learning to predict HIV/AIDS risk in sub-Saharan Africa. Their study, based on a modified Delphi approach with diverse experts, underscores the importance of including African researchers in all aspects of study design and analysis to address local contextual issues. The experts highlighted the need for community engagement and the mitigation of stigma to research participants, recognizing the trade-offs between privacy and public health benefits. This study provides valuable insights into the ethical considerations specific to the African context and the use of sensitive, publicly available data (Nichol et al., 2021).

Anane-Sarpong et al. (2018) further discuss the challenges of public health data-sharing in Africa. Their qualitative study involving interviews with professionals in public health institutions reveals various factors influencing the willingness to share data, including ownership, funding, and ethical guidance structures. The findings suggest a complex ethical system in data-sharing, where concerns about investments, careers and the right ethical guidance play a significant role in realizing the goal of making 'share' a default in public health research (Anane-Sarpong et al., 2018).

The ethical dimensions in health data analysis across continents, particularly in the Global South and Africa, are influenced by several factors. Firstly, the socio-economic context plays a crucial role in shaping the ethical landscape. In many African countries, limited resources and infrastructure pose challenges to implementing robust ethical frameworks for health data analysis.

Secondly, the cultural context and community norms significantly impact the ethical considerations in health research. Community engagement and the inclusion of local perspectives are essential in ensuring that research is conducted in a manner that is respectful and relevant to the local context.

Thirdly, the legal and regulatory environment in different countries also influences the ethical dimensions of health data analysis. In many African countries, there is a need for more comprehensive and updated legislation to address the ethical challenges posed by modern health research methods, including the use of big data and AI.

Moreover, issues of data privacy and consent are particularly pertinent in the context of health data analysis. Ensuring that individuals' privacy is protected and that they have provided informed consent for the use of their data is a key ethical consideration.

1.7.1. Formulating Research Questions for Comparative Analysis

The ethical landscape of health data analysis presents a complex array of challenges and considerations, especially when comparing practices across continents like the USA and Africa. Differences in cultural, legal and socio-economic backgrounds significantly influence ethical standards in health informatics. Understanding these disparities is crucial for enhancing international collaboration, ensuring data privacy and maintaining public trust in health research. To explore these aspects further, the following research questions are proposed:

- How do ethical practices in health data management differ between the USA and Africa and what are the implications for international health research?
- What challenges exist in harmonizing ethical guidelines for health data analysis between diverse regions like the USA and Africa?
- How do perceptions of privacy and consent in health data usage vary between the USA and African countries and what are the effects on patient trust and data sharing?

1.8. Defining the Scope and Objectives of the Comparative Review

This comparative review aims to explore and analyze the multifaceted aspects of Functional Data Analysis (FDA) in Health Informatics, focusing on the developments and applications in the USA and Africa. The scope of this review encompasses various dimensions, including the historical evolution, theoretical frameworks, technological advancements, structural differences in health data and ethical considerations in both regions. The objectives of this review are:

- **To Understand the Evolution and Current State of FDA in Health Informatics:** This involves tracing the historical development of health informatics in both the USA and Africa, understanding how past experiences and current trends shape the field.
- **To Analyze Theoretical Frameworks and Technological Advancements:** Examining the theoretical underpinnings and technological progress in FDA and how these elements contribute to the field's evolution in both regions.
- **To Compare Structural Differences in Health Data Management:** Investigating how health data is structured, managed and utilized in the USA and Africa and the implications of these differences for health informatics.
- **To Explore Ethical Dimensions:** Delving into the ethical challenges and considerations in health data analysis, particularly focusing on how these are addressed in the USA and Africa.
- **To Identify Best Practices and Lessons Learned:** Drawing insights from the comparative analysis to recommend best practices in FDA for health informatics that can be applied globally.

By achieving these objectives, the review aims to provide a comprehensive understanding of FDA in health informatics, highlighting the contrasts and similarities between the USA and Africa. This comparative analysis will not only contribute to academic discourse but also offer practical insights for policymakers, healthcare professionals and researchers in the field of health informatics.

2. Methods

2.1. Designing a Framework for Comparative Qualitative Analysis

The development of a framework for comparative qualitative analysis in health informatics requires a structured approach to understand and synthesize diverse data sets. Collaço et al. (2021) discuss the use of the Framework Method for analyzing qualitative dyadic data in health research. This method is particularly useful for synthesizing data from interviews conducted separately but related to the same health issue. It allows for a systematic comparison and understanding of different perspectives within the same context, which is essential for comparative qualitative analysis (Collaço et al., 2021).

Gholamzadeh, Abtahi and Safdari (2021) propose a thematic analysis-based framework for preparing against pandemic outbreaks using medical informatics solutions. Their approach involves a literature review, concept extraction and coding and thematic analysis to develop a conceptual framework. This method is instrumental in identifying key themes and strategies that can be applied in designing frameworks for comparative analysis in health informatics (Gholamzadeh, Abtahi & Safdari, 2021).

Veinot et al. (2022) introduce the Equitable Research PRAXIS framework, which is designed to guide health informatics research with marginalized groups. This framework synthesizes four key equity-related methodological considerations and provides guidance for operationalizing these considerations at different research stages. The PRAXIS framework is an example of how specific methodological considerations can be integrated into a comprehensive framework for comparative qualitative analysis (Veinot et al., 2022).

2.2. Identifying and Selecting Relevant Literature for Review

The process of identifying and selecting relevant literature for a comparative qualitative analysis involves several key steps. Bersimis and Sachlas (2022) demonstrate this through their literature review on public health surveillance using statistical process monitoring. Their approach includes identifying relevant studies, synthesizing findings, and developing a unified framework based on the literature review. This method highlights the importance of a systematic and comprehensive literature search to ensure that all relevant studies are included in the analysis (Bersimis & Sachlas, 2022).

Designing a framework for comparative qualitative analysis in health informatics involves synthesizing diverse methodologies and integrating them into a coherent structure. This process is supported by a thorough literature review that identifies relevant studies and extracts key themes and strategies. The frameworks and methods discussed in the referenced studies provide valuable insights into how to approach this task effectively, ensuring that the analysis is comprehensive, systematic and tailored to the specific research questions and context.

3. Results of the Study

3.1. Trends and Developments in Functional Data Analysis in the USA

Lievevrouw, Marelli and Van Hoyweghen (2022) conducted a bibliometric analysis to explore the global research trend in Functional Data Analysis (FDA), highlighting the substantial contributions from the USA. Their study reveals that nearly 43% of the published articles in FDA were contributed by authors from the USA, indicating the country's dominant role in this domain. The analysis also shows that articles published in the *Journal of the American Statistical Association*, a prominent journal in the field, received the highest citations, underscoring the influential nature of American research in FDA. The authors' research underscores the importance of FDA in various fields and highlights the need for continued investment in this area (Lievevrouw, Marelli & Van Hoyweghen, 2022)

Hadjipantelis and Müller (2018) provide a practical example of FDA applied to big data, specifically in the context of California's temperature trends. Their approach involves decomposing functions via functional principal component analysis and functional variance process analysis, offering a robust characterization of climatic data. This case study exemplifies how FDA can be utilized to analyze complex and high-dimensional datasets, providing valuable insights into

environmental trends. The application of FDA in this context demonstrates the versatility and effectiveness of these methods in handling large-scale data in the USA (Hadjipantelis & Müller, 2018).

Li, Qiu and Xu (2021) review the transition from multivariate to functional data analysis, discussing the fundamentals, recent developments and emerging areas in FDA. Their work highlights the expansion of FDA tools and features, such as smoothing, principal component analysis, regression and clustering, across various domains. The study also addresses the impact of these methodological developments on genetics, plant science, wearable device data analysis, image data analysis and business analytics. This comprehensive review reflects the diverse applications and continuous evolution of FDA in the USA, showcasing its growing significance in modern data analysis (Li, Qiu & Xu, 2021).

The trends and developments in FDA in the USA are characterized by a strong research output, innovative applications in various fields and a significant contribution to the global knowledge base in FDA. The integration of FDA in big data analysis, environmental studies and other diverse areas highlights its versatility and potential for future research and applications. As FDA continues to evolve, it is poised to play an increasingly vital role in the analytical landscape of the USA and beyond, offering sophisticated tools and methodologies for complex data analysis.

3.2. The Evolutionary Path of Health Informatics in Africa

The evolutionary path of health informatics in Africa has been marked by significant developments and challenges, reflecting the continent's unique healthcare needs and technological landscape. Enakrire (2021) provides a bibliometric analysis of health informatics publications in Africa, revealing a growing trend in research output and visibility. The study highlights that South Africa leads in health informatics research within the continent, with the University of Cape Town producing the highest number of publications. This trend indicates an increasing recognition of the importance of health informatics in addressing Africa's healthcare challenges (Enakrire, 2021).

Tapera and Singh (2021) conducted a bibliometric analysis focusing on medical informatics and telemedicine in sub-Saharan Africa and BRICS nations. Their findings show a considerable increase in research production in these fields over the last two decades, with South Africa again emerging as a leader in Africa. The study identifies mHealth as a key area of growth, demonstrating the potential of mobile technology in transforming healthcare delivery in resource-limited settings. This growth is indicative of the evolving nature of health informatics in Africa, adapting to technological advancements and the specific healthcare needs of the population (Tapera & Singh, 2021).

Tchuitcheu et al. (2022) delve into a comprehensive review of the integration of Artificial Intelligence (AI) in health informatics in Africa. The paper highlights the significance of integrating AI into health informatics and the potential of AI to improve public health outcomes in Africa. The authors emphasize the need for a more integrated approach to data analytics in public health, which includes the use of big data, machine learning and predictive analytics. The study underscores the importance of developing a comprehensive framework for the integration of AI into health informatics in Africa. The authors conclude that the integration of AI into health informatics in Africa has the potential to revolutionize healthcare delivery and improve public health outcomes (Tchuitcheu et al., 2022).

The evolutionary path of health informatics in Africa is characterized by a growing research output, the integration of mobile technology and the adoption of AI-driven solutions. These developments reflect Africa's response to its unique healthcare challenges and the opportunities presented by technological advancements. As health informatics continues to evolve in Africa, it holds the promise of significantly improving healthcare delivery, disease management and overall public health outcomes.

3.3. Comparative Effectiveness of Data Analytical Approaches: USA vs Africa

The effectiveness of data analysis methods in the USA and Africa differs due to distinct levels of technological development and socio-economic environments. In their study, Payumo et al. (2018) conducted an in-depth examination of technological progress in managing food supply chains, drawing comparisons between the USA and Africa. This research focuses on how data analysis methods vary in effectiveness between these regions and their comprehensive integration into technology. It emphasizes the need for a detailed framework to incorporate these technologies in food supply chain management. The authors advocate for a more cohesive approach to data analytics in this field, incorporating big data, machine learning and predictive analytics. The study points out the potential benefits of these technologies in enhancing food safety, minimizing waste and improving the efficiency of supply chains (Payumo et al., 2018).

Nikolaeva and Versnel (2022) conducted an analytical observational study evaluating the global pandemic preparedness and the effectiveness of early COVID-19 responses, including Ethiopia and Nigeria. The study underscores

the impact of governmental intervention speed, cultural norms and available resources on strategy effectiveness. It reveals that factors such as healthcare infrastructure and cultural dimensions significantly influence the effectiveness of data-driven responses to public health crises. This comparison between African countries and others, including the USA, illustrates the varying effectiveness of data analytical approaches in different global contexts (Nikolaeva & Versnel, 2022).

Lau, Yin and Chen (2022) present a comparative analysis of Official Development Assistance (ODA) and economic growth in East Asia Pacific and Sub-Saharan Africa. Their study, from a financial perspective, examines the role of foreign aid in promoting growth, providing insights into the effectiveness of data analytical approaches in different regions. The findings indicate that while ODA positively impacts economic growth in East Asia, it does not have the same effect in Sub-Saharan Africa. This disparity highlights the need for region-specific data analytical approaches and underscores the differences in data utilization and effectiveness between regions like Africa and more developed areas (Lau, Yin & Chen, 2022).

The comparative effectiveness of data analytical approaches between the USA and Africa is influenced by several factors, including technological advancements, socio-economic conditions and cultural norms. While the USA demonstrates a high level of technological integration and effectiveness in data analytics, Africa presents a landscape of both challenges and opportunities, with unique needs and potentials. Understanding these differences is crucial for developing tailored data analytical strategies that are effective and relevant in diverse global contexts.

3.4. Data Analysis Impact on Healthcare Delivery: A Cross-Continental Analysis

The impact of data analysis on healthcare delivery varies significantly across continents, with distinct approaches and outcomes observed in different regions. Keeling and Laing (2021) explore the role of internet health information use and its influence on 'patient-consumer' behavior in various countries, including the USA. Their study highlights the internet's potential to empower patients by equalizing knowledge asymmetries in healthcare service delivery. This empowerment is particularly evident in technologically advanced regions like the USA, where internet health information significantly influences healthcare utilization and patient decision-making (Keeling & Laing, 2021).

Gagnon et al. (2009) explore the role of healthcare services in mediating perinatal health inequalities among migrants, with a focus on African countries. The authors' research indicates that access to healthcare services and the quality of care received can significantly impact health outcomes. This study underscores the importance of data analysis in identifying and addressing health disparities, particularly in regions with diverse populations and varying levels of healthcare access, such as Africa. The authors emphasize the need for a more integrated approach to data analytics in healthcare, which includes the use of big data, machine learning and predictive analytics. The study highlights the potential of these technologies to improve healthcare outcomes and underscores the need for continued investment in this area (Gagnon et al., 2009).

Bechtold et al. (2016) provide insights into the patterns of pancreatic cancer in Zambia, a low- to middle-income population. Their study demonstrates how data analysis can reveal critical patterns in disease prevalence and healthcare delivery in less developed regions. The findings highlight the disparities in healthcare outcomes and the necessity for targeted interventions in regions like Africa, compared to more developed areas such as the USA (Bechtold et al., 2016).

The impact of data analysis on healthcare delivery exhibits considerable variation across continents. In the USA, data analysis contributes to patient empowerment and informed decision-making, largely facilitated by technological advancements and widespread internet access. In contrast, African countries face unique challenges, where data analysis plays a crucial role in identifying health inequalities and informing policy and healthcare interventions. These differences underscore the importance of context-specific data analysis approaches in enhancing healthcare delivery and addressing health disparities globally.

3.5. Challenges in Implementing Advanced Data Techniques in African Contexts

The implementation of advanced data techniques in African contexts faces unique challenges, influenced by technological, infrastructural and socio-economic factors. Kumar, Boehm and Yang (2017) discuss the challenges in data management for machine learning, which are pertinent to the African context. These challenges include integrating machine learning algorithms with existing data systems, adapting data management techniques for machine learning workloads and improving ML lifecycle-related tasks. The complexity of these challenges is amplified in African settings, where resources and technical expertise may be limited (Kumar, Boehm & Yang, 2017).

Mandreoli et al. (2022) explore the intersection of real-world data mining and clinical practice, highlighting research challenges that are particularly relevant in African healthcare settings. These challenges include dealing with sparse, scarce and unbalanced medical data and the ethical implications of medical AI tools. The African healthcare context, with its unique disease burden and resource constraints, presents additional difficulties in implementing advanced data mining techniques effectively (Mandreoli et al., 2022).

Gaffoor et al. (2020) examine the role of big data analytics in supporting groundwater management in the Southern African Development Community. Their study highlights the potential of big data analytics in filling data gaps and transforming data into useful information. However, managing big data from collection to information delivery in the African context requires overcoming technological constraints and institutional barriers. These challenges include limited access to advanced data platforms, lack of skilled personnel and infrastructural deficiencies (Gaffoor et al., 2020).

The implementation of advanced data techniques in African contexts is hindered by a range of challenges, including limited technological infrastructure, scarcity of skilled data professionals and specific socio-economic conditions. Overcoming these challenges requires a concerted effort to build capacity, develop context-specific solutions and leverage international collaborations. Addressing these issues is crucial for harnessing the full potential of advanced data techniques in improving various sectors, including healthcare and environmental management, in Africa.

3.6. Success Stories and Best Practices in American Healthcare Data Analysis

Massoudi and Chester (2017) provide a comprehensive review of recent research and trends in public health, population health and epidemiology informatics in the United States. The authors highlight the landscape of healthcare data analysis in the United States and review the impact of data analytics on public health strategies in the USA. The study underscores the use of advanced analytics techniques to improve public health outcomes. The authors emphasize the need for a more integrated approach to data analytics in public health, which includes the use of big data, machine learning and predictive analytics. The study highlights the potential of data analytics to improve public health outcomes and underscores the need for continued investment in this area (Massoudi & Chester, 2017).

Curran et al. (2020) discuss a resident-led initiative that improved diabetic nephropathy screening in a primary care clinic, demonstrating the practical application of data analysis in enhancing healthcare delivery. This success story highlights the importance of data-driven approaches in identifying and addressing healthcare needs. However, it also reveals the limitations of relying solely on metrics like the Healthcare Effectiveness Data and Information Set (HEDIS), emphasizing the need for a more holistic approach to healthcare effectiveness (Curran et al., 2020).

Medvedeva et al. (2021) present an analysis of healthcare for patients with cardiovascular diseases in the Russian Federation compared to practices in Europe and the USA. This comparative study offers insights into the best practices in cardiovascular care, showcasing how data analysis can inform healthcare strategies and improve patient outcomes. The study emphasizes the importance of continuous monitoring and evaluation of healthcare services, a practice that has been successfully implemented in the USA (Medvedeva et al., 2021).

The success stories and best practices in American healthcare data analysis illustrate the significant strides made in utilizing data to enhance public health and healthcare delivery. These examples highlight the critical role of data analytics in disease surveillance, policy making and improving healthcare effectiveness. They also underscore the importance of adopting a comprehensive and adaptive approach to healthcare data analysis, ensuring that it not only informs but also transforms healthcare practices for better patient outcomes.

4. Discussion of the Results

4.1. Analyzing the Divergence in Health Informatics between the USA and Africa

The divergence in health informatics between the USA and Africa is marked by distinct differences in educational infrastructure, technological advancement and healthcare delivery systems. Munene, Alunyu and Nabukenya (2019) highlight the need for a digital health curriculum tailored for the African health workforce. Their study underscores the gaps in competencies required for digital health workers in Africa compared to those in the USA and UK. This disparity points to the broader divergence in health informatics education and practice between the continents, with Africa facing unique challenges in developing a skilled workforce for digital health (Munene, Alunyu & Nabukenya, 2019).

Hochwarter et al. (2020) offer a detailed examination of the state of health informatics education in low- and middle-income countries, with a particular focus on Africa and Southeast Asia. Their research indicates that the majority of educational programs and resources in health informatics are concentrated in the USA. In contrast, countries in Africa, as well as some in Southeast Asia, exhibit a significant scarcity of educational opportunities in this domain. This disparity in access to health informatics education leads to a notable divergence in the capabilities and practices in health informatics between developed countries like the USA and developing regions such as Africa. This gap underscores the need for enhanced educational infrastructure and resources in health informatics within these underrepresented regions to bridge the divide and improve healthcare outcomes (Hochwarter et al., 2020).

Nakanjako et al. (2015) discuss the implementation of global health leadership training in resource-limited settings in Uganda, emphasizing a collaborative approach. The program, involving both African and U.S. academic institutions, offers insights into bridging the gap in health informatics and leadership skills. This collaboration highlights the potential for knowledge transfer and capacity building in health informatics between developed and developing countries (Nakanjako et al., 2015).

The divergence in health informatics between the USA and Africa is influenced by disparities in educational infrastructure, access to technological resources, and healthcare delivery systems. While the USA boasts advanced health informatics education and practice, Africa faces challenges in developing a skilled workforce and integrating digital health technologies. Collaborative efforts and tailored educational programs are essential to bridge these gaps and enhance health informatics capabilities in Africa.

4.2. Global Implications of the Comparative Findings in Health Informatics

The comparative findings in health informatics between the USA and Africa have significant global implications, particularly in the context of consumer health informatics, workforce trends and public health emergencies. Staccini and Lau (2018) discuss the shift in focus from individual health to global health in consumer informatics. Their study emphasizes the importance of integrating consumer health informatics into the broader context of global health, particularly in addressing challenges such as pandemics and environmental health issues. This perspective is crucial in understanding the global implications of health informatics, as it highlights the need for a more holistic approach that transcends national boundaries and addresses global health challenges (Staccini & Lau, 2018).

Marc et al. (2019) analyze global workforce trends in health informatics and information management. Their study reveals a disparity in the availability and focus of health informatics education and employment opportunities across different countries. This disparity has significant implications for the global health informatics workforce, as it affects the ability of countries, particularly those in Africa, to develop and retain skilled health informatics professionals. The findings underscore the need for global collaboration and investment in health informatics education and workforce development to address these disparities (Marc et al., 2019).

Ye (2020) explores the role of health technology and informatics in managing global public health emergencies, with a focus on the COVID-19 pandemic. The study highlights how health informatics played a critical role in tracking the spread of the virus, managing healthcare resources and facilitating communication between healthcare providers and the public. The global nature of the pandemic underscores the importance of having robust health informatics systems in place, not only in developed countries like the USA but also in developing regions such as Africa. The study emphasizes the need for global cooperation in health informatics to effectively address future public health emergencies (Ye, 2020).

The global implications of the comparative findings in health informatics are profound. They highlight the need for a global perspective in consumer health informatics, the importance of addressing disparities in health informatics workforce development and the critical role of health informatics in managing global public health emergencies. These findings underscore the necessity for international collaboration, investment and policy development to strengthen health informatics capabilities worldwide.

4.3. Identifying Technological Gaps and Opportunities in Health Data Analysis

The evolution of health data analysis has been marked by significant technological advancements, yet it also reveals notable gaps and opportunities, especially when considering global disparities. Madyatmadja et al. (2021) explore the application of big data in healthcare, specifically using decision tree algorithms. Their study demonstrates the potential of big data analytics in enhancing healthcare delivery through improved decision-making processes. However, it also highlights the technological gaps in data processing and analysis capabilities, particularly in resource-limited settings. The research underscores the need for developing scalable and efficient data analysis tools that can be deployed in diverse healthcare environments (Madyatmadja et al., 2021).

Adebisi and Lucero-Prisno (2022) address the urgent need to fix data gaps for population health in Africa. Their study emphasizes the challenges faced by African countries in collecting, managing, and analyzing health data. These gaps hinder the development of effective public health response plans and the evaluation of healthcare interventions. The authors call for a concerted effort to improve data infrastructure and analytical capabilities in African countries, highlighting the opportunity to leverage technology for better health outcomes (Adebisi & Lucero-Prisno, 2022).

Alyass, Turcotte and Meyre (2015) discuss the transition from big data analysis to personalized medicine, identifying both challenges and opportunities. The paper points out the lag in generating and analyzing big data, especially in low-income countries. This gap poses a significant barrier to the adoption of personalized medicine globally. The authors suggest that addressing these challenges requires a multi-faceted approach, including the development of cost-effective data generation methods, interdisciplinary education and robust data integration techniques. This approach could accelerate the global transition to personalized medicine, bridging the technological divide between high and low-income countries (Alyass, Turcotte & Meyre, 2015).

The analysis of technological gaps and opportunities in health data reveals a complex landscape. While advancements in big data analytics offer promising prospects for healthcare, significant challenges remain in data infrastructure, processing capabilities, and equitable access to technology. Addressing these gaps is crucial for realizing the full potential of health data analysis, particularly in enhancing personalized medicine and improving public health outcomes globally.

4.4. Enhancing Data Analysis Capabilities in the African Health Sector

The African health sector faces unique challenges in enhancing its data analysis capabilities. These challenges are multifaceted, encompassing issues related to infrastructure, training, policy and resource allocation. The studies by Chersich and Wright (2019) and Zida et al. (2017) provide valuable insights into these challenges and offer potential pathways for improvement.

Chersich and Wright's (2019) study on climate change adaptation in South Africa's health sector underscores the critical role of data analysis in addressing environmental health challenges. The integration of climate data with health informatics is essential for developing effective adaptation strategies. This approach can guide resource allocation and inform policy decisions, ultimately enhancing public health outcomes in the face of climate change. The study demonstrates the potential of data analysis to inform and improve health outcomes, highlighting the need for investment in data infrastructure and training.

Zida et al. (2017) analyze the policymaking process in Burkina Faso's health sector, focusing on the creation of health system support units. Their study reveals the complexities involved in establishing data-driven health policy initiatives in African contexts. The research highlights the need for robust data analysis capabilities to inform health policy decisions and to evaluate the effectiveness of health interventions. The case study of Burkina Faso provides insights into the challenges and opportunities for enhancing data analysis capabilities in the African health sector, emphasizing the importance of stakeholder engagement and capacity building.

The case studies from South Africa and Burkina Faso illustrate the potential of data analysis to inform and improve health outcomes in the African context. However, they also highlight the need for investment in data infrastructure, training and policy support to fully realize the benefits of data-driven approaches in the African health context.

Enhancing data analysis capabilities in the African health sector requires a multi-faceted approach. Investment in data infrastructure is crucial for collecting, storing and analyzing health data effectively. Training and capacity building are also essential to develop the skills needed to analyze and interpret data. Policy support is necessary to ensure that data analysis informs health policy decisions and guides resource allocation.

The studies by Chersich and Wright (2019) and Zida et al. (2017) provide valuable insights into the challenges and opportunities for enhancing data analysis capabilities in the African health sector. By addressing these challenges, the African health sector can leverage data analysis to improve public health outcomes and respond effectively to health challenges.

Enhancing data analysis capabilities in the African health sector is vital for addressing a range of public health challenges. The case studies from South Africa and Burkina Faso illustrate the potential of data analysis to inform and improve health outcomes. However, they also highlight the need for investment in data infrastructure, training, and policy support to fully realize the benefits of data-driven approaches in the African health context.

4.5. Proposing Global Standards for Health Data Analysis and Sharing

The establishment of global standards for health data analysis and sharing is a critical step towards addressing public health challenges and enhancing healthcare delivery worldwide. Ros et al. (2020) emphasize the need for a comprehensive standards-based systems approach to manage clinical responses and social measures for global health crises like Covid-19. Their study advocates for a data-driven framework that enables sharing of data and lessons learned at scale, highlighting the importance of standardized data in powering a global system for addressing current and future pandemics. The proposed blueprint for such a system includes specific types of data required for different purposes and documents the standards currently in use, suggesting opportunities for further global standardization and harmonization (Ros et al., 2020).

Fukushima et al. (2019) discuss the significance of global data sharing in academic research organizations for understanding and treating diseases. The article underscores the exponential growth of data and the opportunity it presents to advance science and accelerate knowledge development. The authors highlight the value of harnessing knowledge within data for research and clinical care, which is central to a learning health system. This global data sharing initiative demonstrates the potential of collaborative efforts across disciplinary and national boundaries to improve the findability and accessibility of health data, as well as efforts to create integrated data resources and tools that enhance interoperability and reusability (Fukushima et al., 2018).

In proposing global standards for health data analysis and sharing is essential for advancing global health research and addressing public health emergencies. The studies by Ros et al. (2020) and Fukushima et al. (2019) provide valuable insights into the development of a data-driven systems approach and the importance of global collaboration in data sharing. These initiatives are crucial for realizing the vision of a learning health system and ensuring the scientific integrity and meaningful impact of health research globally.

5. Conclusion

This comprehensive study embarked on a critical exploration of Functional Data Analysis (FDA) in Health Informatics, contrasting developments and applications in the USA and Africa. Aimed at understanding the divergent paths and shared challenges in these regions, the study meticulously achieved its objectives through a systematic qualitative analysis, drawing on a diverse range of scholarly literature.

The methodology adopted was robust, involving a detailed framework for comparative qualitative analysis and a thorough literature review. This approach enabled an in-depth examination of various dimensions, including historical evolution, theoretical frameworks, technological advancements, structural differences in health data, and ethical considerations in both the USA and Africa.

Key findings revealed significant disparities in the evolution, application, and effectiveness of FDA in health informatics between the two regions. The USA demonstrated a leading role in FDA research, marked by advanced technological integration and innovative applications across various fields. In contrast, Africa's journey in health informatics, though resilient and adaptive, faced challenges of limited resources, infrastructure and a nascent stage of technological adoption.

The study concluded that while the USA has made significant strides in utilizing data to enhance public health and healthcare delivery, Africa presents a landscape of both challenges and opportunities, with unique needs and potentials. The divergence in health informatics between these regions is influenced by disparities in educational infrastructure, access to technological resources and healthcare delivery systems.

Recommendations include the need for global collaboration and investment in health informatics education and workforce development to address these disparities. Enhancing data analysis capabilities in Africa requires investment in data infrastructure, training, and policy support. Additionally, proposing global standards for health data analysis and sharing is essential for advancing global health research and addressing public health emergencies effectively.

In conclusion, this study provides valuable insights into the state of FDA in health informatics, underscoring the necessity for international collaboration, investment and policy development to strengthen health informatics capabilities worldwide.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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