

Research publication in long term athlete development: a systematic review and bibliometric analysis of Scopus database in 2009 – 2023

Publicación de investigación en el desarrollo del atleta a largo plazo: una revisión sistemática y análisis bibliométrico de la base de datos Scopus en 2009 – 2023

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Abstract. This study inquired about Long-Term Athlete Development (LTAD) research development and impact. The study was conducted using a bibliometric analysis and systematic review. There were 100 top citation research articles published between 2009 to 2023 and selected from SCOPUS research journal databases by using the keywords "Long Term Athlete Development" and "LTAD". Furthermore, 10 top citation articles were further investigated by systematic review methods. The study outlines the predominance of journal articles as the main conduit for LTAD discourse, with a notable average citation rate underscoring their influence. The United Kingdom (UK) leads in contributions and citations. The geographical distribution showcases the global engagement and diverse perspectives within LTAD research. The examination reveals an initial focus on fundamental sports training and coaching roles, progressively expanding to include practical LTAD applications, demographic, social dynamics, and physiological nuances. This trajectory demonstrates a multidisciplinary approach that integrates several aspects of athlete development. It also emphasizes the need for more thorough longitudinal research to provide empirical support for the principles of LTAD in a variety of cultural and athletic contexts. Even with the breadth of research, empirical, longitudinal studies are still required to confirm the effectiveness of LTAD models in a variety of cultural and sports contexts. The review calls for enhanced international collaboration to further consolidate LTAD research and practice, advocating for a holistic and inclusive understanding of athlete development that integrates gender and social inclusion.

Keywords: youth athlete training, youth athlete coaching, athletic performance, sport coaching

Resumen. Este estudio investiga el desarrollo y el impacto de la investigación sobre el Desarrollo a Largo Plazo del Atleta (LTAD). El estudio se llevó a cabo mediante un análisis bibliométrico y una revisión sistemática. Se seleccionaron 100 artículos de investigación con mayor número de citas publicados entre 2009 y 2023, extraídos de las bases de datos de revistas de investigación de SCOPUS utilizando las palabras clave "Long Term Athlete Development" y "LTAD". Además, 10 artículos con mayor número de citas fueron investigados en mayor profundidad mediante métodos de revisión sistemática. El estudio destaca la predominancia de los artículos de revistas como el principal medio para el discurso sobre LTAD, con una notable tasa promedio de citas que subraya su influencia. El Reino Unido (UK) lidera en contribuciones y citas. La distribución geográfica muestra la participación global y las diversas perspectivas dentro de la investigación sobre LTAD. El examen revela un enfoque inicial en el entrenamiento deportivo fundamental y los roles de entrenamiento, que se expande progresivamente para incluir aplicaciones prácticas de LTAD, dinámicas demográficas y sociales, y matices fisiológicos. Esta trayectoria demuestra un enfoque multidisciplinario que integra varios aspectos del desarrollo del atleta. También se enfatiza la necesidad de una investigación longitudinal más exhaustiva para proporcionar apoyo empírico a los principios de LTAD en una variedad de contextos culturales y deportivos. A pesar de la amplitud de la investigación, aún se requieren estudios empíricos y longitudinales para confirmar la efectividad de los modelos de LTAD en diversos contextos culturales y deportivos. La revisión aboga por una mayor colaboración internacional para consolidar aún más la investigación y práctica de LTAD, promoviendo una comprensión holística e inclusiva del desarrollo del atleta que integre la inclusión de género y social.

Palabras clave: entrenamiento de jóvenes deportistas, entrenamiento de jóvenes deportistas, rendimiento deportivo, entrenamiento deportivo

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Introduction

The development of athletes in sports achievements has a very important role in producing quality athletes who are able to excel in sports competitions (Staub, Zinner, Bieder, & Vogt, 2020). Developing outstanding sports athletes is a crucial aspect in creating a generation of athletes who are superior and proud (Ihsan, Nasrulloh, Nugroho, & Kozina, 2024). This is important to do because coaching sports achievements are an integral part of a nation's sports culture (Nuno Leite, Baker, & Sampaio, 2009). Athletes who are able to achieve achievements at the national or even international level become heroes and inspirations for many people. However, behind this success, there is an intensive and

structured coaching effort and process that the athlete must undergo (Beaudoin, Callary, & Trudeau, 2015).

Development of performance sports athletes is a series of programs designed to develop athletes' potential to the maximum (Nour-Frías, Fernández-Ozcorta, & Ramos-Véliz, 2024). This program involves various aspects such as physical and technical training (Temm, Standing, & Best, 2022), mental and psychological approaches (Bhattacharya, Chatterjee, & Mondal, 2022), understanding of game tactics and strategy, as well as attention to health and nutritional aspects (Amawi et al., 2022). Coaching high-performance sports athletes also involves the important role of coaches and other quality support teams (Jang & So, 2017). The implementation of Long Term Athlete Development

(LTAD) is one of the key aspects in ensuring the development and success of athletes in various sports (Lachance, 2014). LTAD is an approach designed to develop athletes' potential to the maximum through continuous and structured planning (Fullerton, Gaudreault, & Royce, 2023).

Sport is not just about current achievements, but also about creating the foundation for a successful future (Serrano, Dos Santos, Sampaio, & Leite, 2013). The application of LTAD allows coaches, sports federations, and athletes to look at a longer time period (Banack, Bloom, & Falcão, 2012). LTAD helps athletes develop their skills progressively as they gain age and experience (Fiander, Jones, & Parker, 2014). This ensures that athletes have a solid foundation to face higher levels of competition in the future. Through a structured approach, LTAD also pays attention to health and fitness aspects (Neto, Parent, & Kennedy, 2021). This includes introducing athletes to exercises that minimize the risk of injury and ensure good recovery after injury (Romero-Caballero, Varela-Olalla, Collado-Lázaro, & Álvarez-Salvador, 2022).

Several previous studies also support the positive results of LTAD. Research on long-term athlete development in a group of athletes aged 10 to 12 years, turned out to have a significant effect on physical development (Sulistiyono et al., 2021). Submaximal variables (e.g., lactate/anaerobic threshold and muscle work efficiency) and maximal performance indices (e.g., peak speed/watts during performance testing) also increased (Staff, Solli, Osborne, & Sandbakk, 2023). This research shows the importance of LTAD in developing athlete performance. However, the data in the field still shows different facts, such as the case in the United States with 40 million children who want to enter sports in college and professionally, but the number of athletes who reach that level is very low (NCAA, 2020).

There are only 7.3% of high school football players could play in the NCAA and 1.6% can play for a professional league. Many young athletes who have the potential to become great athletes are forced to enter the specialization stage from an early age, especially in Indonesia. In fact, there is research that shows that almost half of the high school students surveyed have had to choose to focus on one sport since childhood or adolescence (Buckley et al., 2017). This is also rational if you follow the quote from previous research which says that athletes must go through 10,000 hours of practice to become experts in a particular field (Macnamara & Maitra, 2019). Some sports such as gymnastics and figure skating also encourage specialization from an early age (Goodway & Robinson, 2015).

But this is all also refuted by research that proves the good results of LTAD. United States Hockey has started developing this method in 2019. They won 4 consecutive gold medals in the Junior Hockey World Championship. It turns out that early sports specialization and training young athletes like professionals as a way to achieve suc-

cess is refuted by these numbers. Because LTAD emphasizes fun and activities that are appropriate to the stages of development. USA Hockey saw a 33% increase in U-8 players and a 37% increase in female athletes, even as several other countries saw declines in sports participation at that age (Perreault & Gonzalez, 2021).

LTAD is not only about the physical aspect but also about the mental aspect (Lim & O'Sullivan, 2016). It helps athletes develop the mental resilience, concentration, and tactical thinking abilities required in high-level competition (A P Murphy, Duffield, Kellett, & Reid, 2016). LTAD also covers aspects of a healthy lifestyle, such as good diet and stress management (Fuentes-García, Collado-Mateo, & Estévez-López, 2021). This helps athletes develop healthy habits that will help them on and off the field. With its focus on long-term development, LTAD can help athletes maintain their high performance for years, even throughout their careers (Born, Lomax, & Romann, 2020).

Sports federations and countries that implement LTAD well often have a competitive advantage at the international level (Perri et al., 2023). Athletes who have passed the LTAD stages well have great potential to win medals in various international competitions. However, LTAD does not only apply to elite athletes but also applies to all age levels and skill levels (Owen et al., 2023). This means that everyone has the opportunity to thrive in the sport they love. A lot of research related to LTAD has also been carried out, but until now the trend is still not focused and is still specific to certain sports.

This bibliometric research aims to see the development of LTAD research trends in the last 10 years.

1. To analyze LTAD research document type in the 100 Top Citation Research Article
2. To evaluate the most countries contributed LTAD research in 100 Top Citation Research Article
3. To analyze the keyword connection of LTAD research in the 100 Top Citation Research Article
4. To analyze the keyword trends of LTAD research in the 100 Top Citation Research Article
5. To analyze the top 10 cited publications in LTAD research in the 100 Top Citation Research Article

Materials and Methods

This type of research is a Bibliometric Analysis with Systematic Review. The article search was conducted using a comprehensive strategy in the SCOPUS research journal database on October 11th, 2023. The keywords used "Long Term Athlete Development" and "LTAD". Furthermore, there were 100 top citation research articles in Long Term Athlete Development (LTAD) published in the since 2009 to 2023. There were 10 top citation articles were selected for this systematic review. For standard operationalization, this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Figure 1).

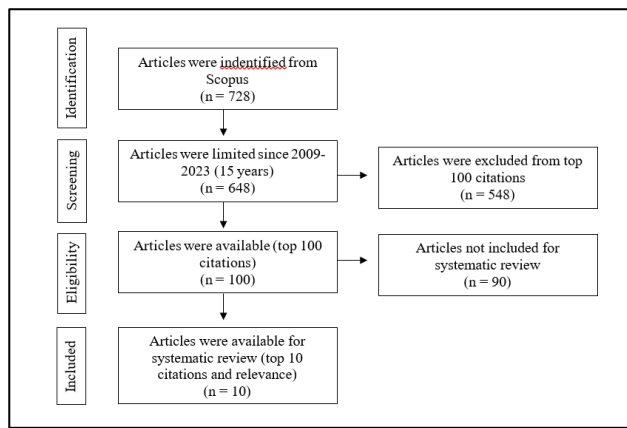


Figure 1. PRISMA Flowchart of the Article Selection Process

Result

Document Type

Document type in the 100 Top Citation Research Articles of LTAD comes from journal articles with 93 articles from one hundred documents (Table 1). Articles are not only the document type that dominates in number but also in impact, with a total of 1553 citations. This translates to an average of 16.70 citations per article, indicating that articles are the primary channel through which LTAD research is disseminated and through it most influence subsequent studies. The predominance of articles is evidence of the dynamic and evolving nature of LTAD research, where peer-reviewed journals act as the backbone for advancing knowledge, testing new theories, and challenging existing paradigms (Table 1).

Table 1.
Document Type of Top Hundred Cited Papers

Document Type	<i>f</i>	Total Cited	Mean
Articles	93	1553	16.70
Book Chapters	6	16	2.67
Conference Papers	1	13	13.00
Total	100	1582	15.82

There are six book chapter publications with a total of 16 citations. Their citation average was a moderate 2.67, which may reflect the deeper and more comprehensive exploration of topics that the book chapters offer. While not having the same reach as a journal article, a book chapter in an edited volume can delve into the nuances of LTAD, offering a rich contextual discussion that goes beyond the scope of the article. They often serve as key sources for in-depth reviews and theoretical frameworks.

One conference paper managed to find its place among the most cited documents, with 13 citations. This is especially remarkable because conference papers are usually considered preliminary findings or work in progress. The fact that these conference papers have an average number of citations comparable to journal articles, namely 13.00, suggests that they present very novel or significant research that is of interest to the LTAD community.

If we look at the total number of citations of 1582 for all the top hundred documents, the average citation is

15.82. This figure summarizes the overall citation impact of the combined document types and is an indicator of the significant scholarly engagement that LTAD research has received over the past decade and a half.

In summarizing these statistics, we must acknowledge the inherent characteristics of each type of document. Articles, often subjected to rigorous peer review, tend to present the most recent and empirically validated research, which may explain the higher citation rates. Book chapters, while contributing less to the citation count, nonetheless provide an important platform for more extensive and contemplative scholarship. The impact of conference papers, on the other hand, emphasizes the importance of academic conferences as forums for presenting cutting-edge research and fostering scholarly discourse, which can have disproportionate influence within the field.

This bibliometric data describes a field supported by a constant flow of new research findings, communicated primarily through articles in scientific journals. It also highlights the importance of different forms of scientific output, each playing a different role in the dissemination and development of knowledge in LTAD research. Looking ahead, it will be interesting to see how this trend develops with the emergence of new research platforms and communications technologies.

Top 10 Countries

In the 100 most cited publications in the field of Long-Term Athlete Development (LTAD), we see the significant role of countries in advocating and advancing knowledge in this area. From the data provided, it can be seen that these ten countries are not only active in producing quality research but have also succeeded in gaining widespread recognition through citations (Table 2).

Table 2.
Top 10 Countries Contributed in the Top Hundred Cited Publications in LTAD

Document Type	<i>f</i>	Total Cited	Mean
United Kingdom	37	1128	582.50
United States	17	387	202.00
Australia	17	509	263.00
Canada	16	188	102.00
Germany	8	61	34.50
South Africa	7	24	15.50
Portugal	7	130	68.50
Ireland	6	49	27.50
New Zealand	5	270	137.50
Japan	5	9	7.00
Total	125	2755	1440.00

The United Kingdom topped the list with a striking number of contributions, namely 37 documents that had an astonishing 1128 citations, with an average per document of 582.5. This indicates that research originating from the UK is not only large in quantity but also highly influential within the LTAD community, reflecting the quality and innovation presented by researchers from that country.

The United States and Australia each contributed 17 documents, but with different citation impacts. Even though the number of documents contributed is the same, Australia has a higher number of citations with a total of 509

citations and an average of 263 per document, compared to the United States which has a total of 387 citations and an average of 202 per document. This may reflect the intensive and specific focus of Australian research in LTAD or may also be due to other factors such as strong international collaboration networks.

Canada, with 16 documents, makes fewer contributions than the previous two countries but remains important with 188 citations and an average of 102 per document. Meanwhile, Germany, with eight documents, shows a total of 61 citations and a per document average of 34.5, indicating that its contributions may focus more on quality than quantity.

South Africa and Portugal, with seven documents each, show quite significant differences in the total citations received. South Africa with 24 citations and an average of 15.5 per document, while Portugal with 130 citations and an average of 68.5 per document, indicates that although they are similar in number of publications, the impact of Portugal is felt more strongly in the LTAD discourse.

Ireland, with six documents, contributed 49 citations and a per document average of 27.5. This may indicate that research from Ireland is having a consistent influence, although not as much as other major contributors. Meanwhile, New Zealand and Japan, each with five documents, show a stark contrast in the number of citations. New Zealand with a total of 270 citations and a per document average of 137.5, indicates a strong presence in LTAD, whereas Japan with only nine citations and a per document average of 7, may indicate that LTAD research in Japan has not received widespread recognition (Figure 2).

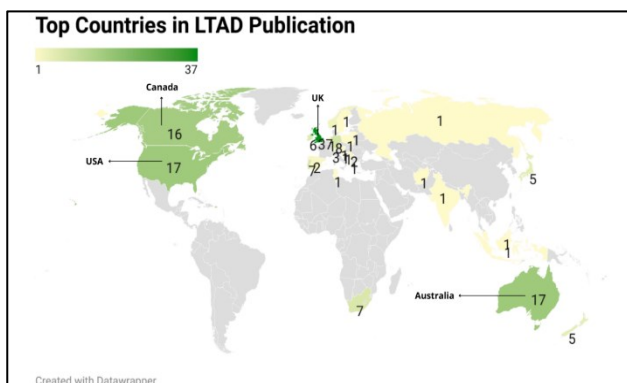


Figure 2. Map of Countries Contributed in LTAD Top 100 Citation Research Publication

Overall these data, with 125 documents from ten countries and a total of 2755 citations, provide an average of 1440 citations, reflecting not only the involvement and dedication of these countries in LTAD research but also the diversity and richness of the perspectives they bring. Each country uniquely contributes to the global study of LTAD, and this enriches our understanding of how athletes are developed across different cultural contexts and sports education systems. In the future, expansion and diversification of contributions from other countries will be highly anticipated

to provide a more inclusive and comprehensive insight into global LTAD studies.

Keywords Connection and Trends

We can see a keyword map or visualization of the analysis of keywords and topics frequently used in Long-Term Athlete Development (LTAD) publications (Figure 3). This information shows how often certain keywords appear together in scientific literature, indicating conceptual relationships between various aspects of LTAD research. The focal points in LTAD literature are prominently the terms "sport" and "coach," underscoring their pivotal roles in athlete development. These keywords signify that training and sports are central themes in LTAD discussions, with a significant emphasis on the coach's integral role. The proximity of "ltad approach" and "long term athlete development" to "sport" and "coach" highlights that LTAD is not merely a conceptual framework but a practical approach applied to athlete training and development. Keywords like "participation," "physical activity," and "implementation" form interconnected groups, indicating a strong focus on applying LTAD to promote participation and physical activity across all levels of sports involvement.

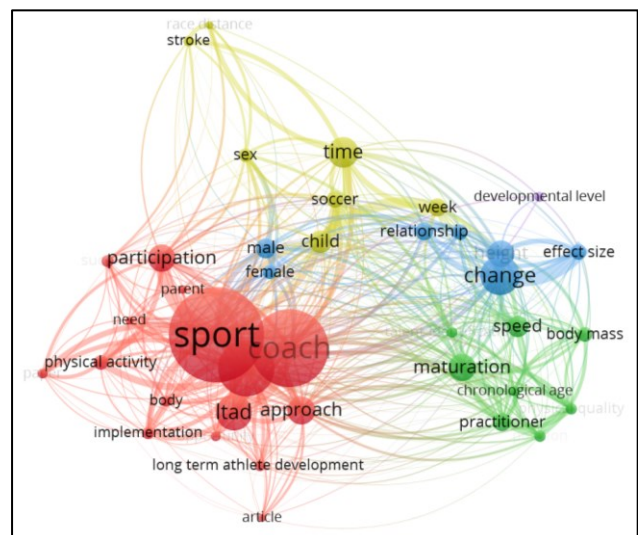


Figure 3. Keywords Connection in LTAD Top 100 Citation Research Publications

In addressing demographic and social aspects, linked words such as "male," "female," "child," "parent," and "need" underscore the LTAD literature's coverage of gender, age, parental roles, and individual needs in athlete development. The interconnected terms "time," "week," "change," "maturation," and "chronological age" emphasize the temporal dimension in athlete development, stressing the significance of growth, maturation, and changes over an athlete's career.

The inclusion of "soccer" as a representative of team sports, linked to "sex" and "relationship," signifies the importance of gender dynamics and interpersonal relationships in certain team sports within LTAD. Words like "speed," "body mass," and "practitioner" being connected

draw attention to the physiological and professional elements within LTAD, suggesting that research in this field encompasses an understanding of physical factors like speed and body mass, as well as the roles of practitioners or professionals supporting athletes.

The peripheral term "article" indicates that these discussions are often found in research articles, highlighting literature as a primary information source in LTAD research. This keyword map provides valuable insights into the intricate network of themes and concepts in LTAD research, aiding in understanding the current research scope, trends, and identifying potential gaps in the literature.

Keyword Trends

The visual representation of keywords in Long-Term Athlete Development (LTAD) research illustrates the progression of topics over time, with color serving as a temporal indicator (Figure 4). In the initial blue phase, the research primarily centered around foundational concepts like "sport" and "coach," underscoring a strong emphasis on understanding the fundamental aspects of sports and recognizing the pivotal role of coaches in athlete development. These early investigations laid the groundwork for subsequent LTAD literature, emphasizing the importance of a systematic approach to sports training.

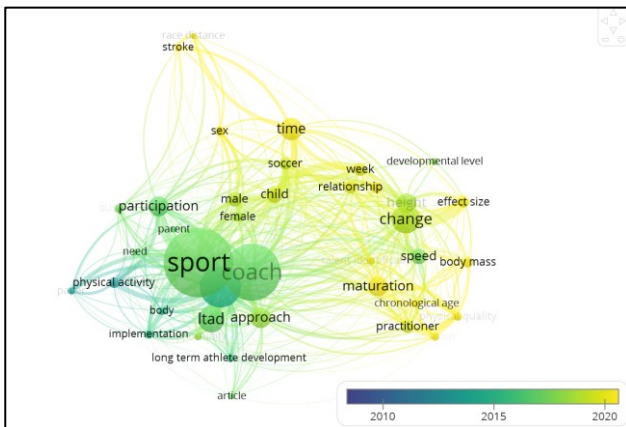


Figure 4. Keywords Trend in LTAD Top 100 Citation Research Publication

Transitioning into the green phase, there is a noticeable surge in discussions related to "participation" and "physical activity" in the context of LTAD implementation. This shift suggests a move towards practical applications of LTAD

theories, aiming to promote broader engagement in sports and physical activities. It also indicates a heightened awareness of the significance of regular physical activity and the integration of LTAD programs into everyday life.

Moving further into the green to yellow phase, there is a pronounced focus on demographic and social aspects, including considerations of gender ("male," "female") and familial influences ("child," "parent"). This phase signals a growing acknowledgment of factors such as age, biological maturity ("maturation"), and family support in shaping athlete development. The discourse expands beyond individual athletes to encompass the social and cultural contexts in which their development takes place.

Approaching the conclusion of the yellow period, there is a discernible uptick in attention towards physiological factors such as "speed" and "body mass," coupled with an exploration of how these factors are measured and enhanced ("effect size"). This suggests a maturation of LTAD research towards a more analytical and data-driven approach, with a focus on detailed examinations of training program effects on physical improvements. The emerging visibility of practitioners ("practitioners") underscores the recognition of specialists' roles in implementing effective LTAD programs.

In summary, these visualizations offer a comprehensive view of the evolution of LTAD research spanning more than a decade. The progression from foundational training and coaching principles to practical applications, social considerations, and finally, results-oriented and measurement-focused research, demonstrates the expanding and deepening landscape of LTAD studies. This evolution encompasses diverse disciplines and addresses the varying needs of athletes across backgrounds and developmental stages.

Top 10 Cited Publications

The results of the research in this literature review are presented below (Table 3). The five primary subjects referenced from the top ten publications in LTAD are covered in the summary of the Top 10 referenced Publications in LTAD. This draws attention to the various methods and conclusions about the assessment and application of LTAD models, the particulars of exercises based on age and developmental stage, and the necessity of more study in the following domains:

Table 3. Top 10 Cited Publication

Author	Total Cited	Research Purposes	Methods	Results
(R S Lloyd & Oliver, 2012)	345	Assessing young athletes' physical performance using the LTAD method.	Article Review	In the prepubescent stage, strength, FMS, speed, and agility are prioritized. During adolescence, power and hypertrophy become increasingly significant.
(P Ford et al., 2011)	269	Examine the trainability of the physiological fitness components found in the LTAD model to see whether this has been extensively captured in the model's prescriptions and to assess the notion of "windows of opportunity" directly.	Article Review	Without a doubt, the approach is successful in providing coaches with a framework based on tenable concepts. However, there is no evidence to support the LTAD claims from the components covered in this research (anaerobic and aerobic performance, physical literacy), maybe because there are so many physiological elements influencing performance.
(R S Lloyd et al., 2016)	236	Encourage the benefits of a lifetime of healthy physical exercise, (b) support a	Literature Review	Long-term athletic development has been advanced recently, but more study is still needed because there aren't

Table 3.

Top 10 Cited Publication

Author	Total Cited	Research Purposes	Methods	Results
		more cohesive and all-encompassing approach to long-term athletic development, and (c) help all boys and girls avoid or reduce injuries sustained by participating in sports.		enough long-term, carefully controlled empirical studies at this time. More research is needed in several important areas, including a deeper understanding of youth training, how training interacts with growth and maturation, and the effects of long-term approaches to athletic development on injury risk, physical performance, and health and well-being.
(R S Lloyd, Oliver, Hughes, & Williams, 2012b)	89	Analyze how a 4-week plyometric training program affects the measurements of RSI and leg stiffness in youth aged 9 to 15 years.	Experimental Study	Boys aged 12 and 15 showed a substantial improvement in leg stiffness performance after a 4-week plyometric training program. Relative limb stiffness does not seem to have an impact on these beneficial training effects, indicating that they are not size-dependent. The 12-year-old boys who took part in the plyometric exercise also saw a significant improvement in their RSI performance.
(R S Lloyd, Oliver, Hughes, & Williams, 2011b)	83	Analyze how the SSC develops in children of different ages and developmental stages by administering a variety of performance assessments.	Experimental Study	While it is highly likely that windows of faster adaptation would exist for male youths' SJ and CMJ height and RSI, findings regarding leg stiffness would imply that fast-SSC function might follow a different developmental trend.
(Barr, Sheppard, Gabbett, & Newton, 2014b)	65	Recognize how senior and junior international rugby players develop these attributes.	Experimental Study	Senior rugby players can be distinguished from junior players primarily by their sprint momentum, and younger players can make significant adjustments when they advance to senior rugby. Players in their early 20s seem to reach their peak speed, but sprint momentum seems more trainable.
(N Leite, Baker, & Sampaio, 2009)	64	Determine how many and what kinds of sports experienced team sport players participate in during the early phases of their long-term athlete development.	Mixed Method	There is a lot of variance between and within sports, but athletes usually start playing sports when they are between the ages of six and ten. At every level of involvement, the pattern of participation in both particular and non-specific (team, individual, and combat) sports shows an increase in the number of activities until early adolescence.
(R S Lloyd et al., 2013)	56	Examines the data showing how development, maturation, and training affect children's and teenagers' change of direction speed and cognitive processing, and how these impacts taken together may affect agility.	Literature Review	The paucity of research on the evolution of agility between childhood and adolescence has highlighted the existing state of knowledge gaps on the impact of maturation on agility performance.
(A P Murphy, Duffield, Kellett, & Reid, 2014)	48	Examine the differences in elite junior tennis player perceptions of internal strain and notational analysis of external load between coaches and athletes.	Quantitative Research	According to regression studies, targeted session exertion and coach drill RPE accounted for 54.5% of the variance in coach RPE, whereas peak HR and drill RPE explained 45.3% of the variance in athlete session RPE.
(M Lang & Light, 2010)	44	Curious about how national sports organizations have customized the model to meet their unique needs and how this is operationalized and given locally in terms of interpretation and execution.	Qualitative Research	The coaches in this survey had the biggest complaints about The Swimmer Pathway, primarily regarding the effect of high volume on technique improvement and, to a lesser extent, motivation. It is obvious that any training program with the goal of long-term development must emphasize the significance of strong learning techniques before the age of 13.

The Importance of Pre-Pubertal and Adolescent Phases

Strength, FMS (Functional Movement Screen), speed, and agility become priorities in pre-puberty according to Lloyd and Oliver's (2012) research using the LTAD paradigm, however power and hypertrophy become more significant during adolescence. These results highlight how crucial it is to tailor training regimens for young athletes according to their age and developmental stage.

Evaluation of The LTAD Model

Ford et al. (2011) evaluated the idea of "windows of opportunity" and looked at the physiological fitness component of the LTAD model in connection to coaching to see if this has been included in the model adequately. The research findings indicate that while the LTAD model offers a plausible training framework, there is insufficient data to substantiate the claims made by LTAD. This is probably because there are numerous physiological aspects that impact performance.

Long Term Athletic Development

The goal of Lloyd et al. (2016) is to provide a more comprehensive and integrated approach to long-term athletic development in addition to reducing or eliminating sports-related injuries. Despite the recent advancements in LTAD, they discovered that more research is still required, especially with regard to youth training, the relationship between training and growth and maturity, and the effects of long-term methods on health, injury risk, and physical performance.

Plyometric Training in Children

Lloyd et al. (2012) investigated how a four-week plyometric training program affected children's RSI (Reactive Strength Index) and leg stiffness at the ages of nine, twelve, and fifteen. The results of this experimental study demonstrated that plyometric training had a substantial positive impact on leg stiffness performance in boys aged 12 and 15, and that the benefits of training were not influenced by body size.

Development of SSC Function in Children

Lloyd et al. (2011) examined the development of short-stretch cycle (SSC) function using a variety of performance tests in children with different age ranges and maturity levels. They concluded that there was a 'window' of accelerated adaptation to SJ (Squat Jump) and CMJ (Counter Movement Jump) heights as well as RSI in male youth, although the leg stiffness results suggest that rapid SSC function may follow a different developmental trend.

Discussion

The Youth Physical Development Model is a new approach to long-term athletic development that focuses on developing multiple fitness qualities throughout a person's lifetime. Previous models have categorized training methods according to chronological age groups, which has limitations. The Youth Physical Development Model uses objective analysis to develop physical performance in young athletes. It turns out that long-term athlete development practices have been recommended for the last two decades. However, there is limited research addressing the knowledge and skills required by practitioners to maximize long-term athlete development (Till et al., 2022).

The development of Long-Term Athlete Development (LTAD) research trends over the last decade requires an in-depth understanding of the various aspects that have been discussed in the literature (Varghese, Ruparell, & LaBella, 2022). Bibliometric analysis shows a comprehensive picture of the dynamics of research focused on athlete development over time. Journal articles, as the dominant publication format in LTAD, represent the gold standard in the dissemination of scientific knowledge, with peer review as a key mechanism in validating research (Rhodri S. Lloyd & Oliver, 2012). The existence of book chapters and conference papers, although not as numerous as articles, shows the importance of various mediums in disseminating insights in the field of LTAD (Paul Ford et al., 2011a).

The geographical contribution to LTAD research is evident through work originating from countries with strong traditions in sports and physical education research, such as the United Kingdom and the United States (Rhodri S. Lloyd et al., 2014). This confirms that athlete development is not only influenced by individual factors but also by support systems and national policies that allow this kind of research to develop (Barr, Sheppard, Gabbett, & Newton, 2014a). Evaluation of the physiological and fitness components in the LTAD model reveals that there is still uncertainty in some of the model's claims, indicating the need for more empirical studies (Paul Ford et al., 2011b).

At the same time, there is a growing consensus that training appropriate to the athlete's stage of physical and psychological development is essential (Granacher & Borde, 2017). In particular, studies evaluating the pre-pubertal and adolescent phases suggest that the type of training must be adapted to the physiological changes that occur in young athletes (Ouergui et al., 2021). These findings reinforce the

importance of understanding growth and maturation processes in athletes and how these influence training programs (Cho & Roh, 2019).

Research exploring plyometric training and its effects on leg stiffness and Reactive Strength Index (RSI) in children provides evidence of the benefits of this training in young athletes (R S Lloyd, Oliver, Hughes, & Williams, 2012a). Interestingly, this study shows that the effects of training are independent of body size, providing valuable insight into how training can be tailored for young athletes who are at different stages of development.

On the other hand, research evaluating the function of the short-stretch cycle (SSC) in children found that there may be 'windows of accelerated adaptation' for Squat Jump (SJ) and Counter Movement Jump (CMJ) heights in male youth (R S Lloyd, Oliver, Hughes, & Williams, 2011a). However, these findings also suggest that the rapid development of SSC function may follow a different trend, highlighting the complexity of athlete development and the need for further research in this area.

Technological advances in the last decade have also allowed LTAD research to become more sophisticated by including more in-depth data analysis and real-time monitoring of athlete performance (Alistair P. Murphy, Duffield, Kellett, & Reid, 2014). For example, research exploring perceptions of internal and external training load in junior tennis athletes shows the potential of regression analysis in understanding athletes' experiences during training (Phibbs et al., 2018).

Research into how national sporting bodies adapt to the LTAD model highlights the importance of local interpretation and implementation of best practice. In this context, research by Lang & Light (2010) shows coaches' concerns about the impact of excessive training volume on the technique development and motivation of young athletes, emphasizing the need to balance training load with skill development (Melanie Lang & Light, 2010).

This discussion, based on the most widely cited research, shows a complex, multidisciplinary picture of athlete development. This suggests that while LTAD research has advanced significantly, there is still room for a deeper understanding and practical application of research findings. Collaboration between researchers, practitioners, coaches, and policymakers remains critical to advancing the field and supporting sustainable and holistic athlete development.

Conclusion

This bibliometric research confirms that LTAD research is a dynamic field with many significant developments in the last decade. However, there are still gaps that need to be filled, such as the need for well-controlled longitudinal studies to empirically test the principles of LTAD. Additionally, there needs to be increased international collaboration in research to ensure that LTAD knowledge can be adapted and applied effectively across different cultural contexts and sports systems. Finally, future research should

strive to better integrate aspects of gender, social inclusion, and technology in athlete training and development.

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