Data-Driven Monitoring of Current Situation, Trends, and Changes in Children´s Physical Fitness

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Dissertation

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Summary

Physical fitness is known to be an important resource for health. As there is a reciprocal relationship between physical fitness and physical activity, it is also a key component of an active lifestyle, now and in the future. Research on physical fitness in childhood is particularly important, as it is the critical period for the development of physical fitness, thus laying the foundation for more specific motor skills and movement patterns, and even encouraging or discouraging individuals to engage in physical activity.

Monitoring is already being used in several areas of life. In the case of children's physical fitness, systematic and continuous monitoring allows not only to assess current levels, but also to identify trends and changes, and to analyze patterns in physical fitness. The findings provide the basis for further strategies and interventions to promote physical fitness. In order to assess an individual´s level of physical fitness, tests items are conducted on a product level to make the latent construct apparent on an obvious level.

However, in order to generate evidence-based information and to enable knowledge of children´s physical fitness for population health monitoring, a large amount of data assessed with standardized test batteries over a long period of time is needed. This is lacking in recent research on physical fitness, even though open data is gaining importance and providing new opportunities for sufficient monitoring.

Based on this, the dissertation aims to use the data pooling approach and analyze data exploratory to provide monitoring of current situation, trends, and changes in children's physical fitness.

Four papers were included in the dissertation and an additional best practice example was presented. To provide an overview of the current state of research on trends in childhood physical fitness, a review of large-scale epidemiologic studies was conducted. Based on the findings, we discussed the possibilities of pooling data on physical fitness to overcome existing methodological problems in assessing trends. Further analyses were therefore performed utilizing pooled samples. We used simple statistical methods, e.g. ANOVAs, but also complex linear mixed models and considered the COVID-19 pandemic as an influencing factor of physical fitness. Results were reported comprehensively and specifically for the different dimensions of physical fitness. With the Fitness Barometer, we translated the evidence-based findings in into practice.

There has been an overall declining trend in children´s physical fitness internationally, but a stagnation on a low level has been observed for most recent years. The findings vary for the specific dimensions, but are most evident for endurance and strength. With the onset of

COVID-19, the trend changed negatively, but is additionally differentiated by other variables, e.g. rural communities, high pre-pandemic fitness.

We identified an urgent need for global standardization of theoretical constructs and test batteries to further extend the pooling of different data sets and to allow comparisons of determinants of physical fitness across different groups. However, data-driven analyses are useful and valuable to analysing and identifying trends, patterns, and changes. To translate evidence-based monitoring into practice, easy-to-understand categories and practical implementations should be presented to decision makers and the public.

Due to stagnation on a low level and the fact that previous generations of children were fitter, even small losses during the critical learning years affect the long-term development of physical fitness. Standardized and continuous monitoring based on pooled datasets identifies the current situation, trends and changes in children's physical fitness. This can be used to make evidence-based decisions about policies and programs to support children's development. Further effort should be given in collaborative research to further strengthens the opportunities of data access and development of common approaches.

Zusammenfassung

Die körperliche Leistungsfähigkeit ist eine der Hauptressourcen für die aktuelle und zukünftige Gesundheit eines Individuums. Sie steht dabei in einer wechselseitigen Beziehung zur körperlichen Aktivität und ist folglich ein bedeutender Faktor für einen aktiven Lebensstil über die gesamte Lebensspanne hinweg. Im Kindes- und Jugendalter kommt der Entwicklung der körperlichen Leistungsfähigkeit eine entscheidende Rolle zu, da sie die Grundlage für die weitere Ausbildung und Entwicklung von variablen und anpassungsfähigen Bewegungshandlungen und -mustern ist. Die individuelle Ausprägung der körperlichen Leistungsfähigkeit fördert oder hindert eine Person körperlich aktiv zu sein. Umgekehrt beeinflusst eine hohe körperliche Aktivität die Entwicklung der körperlichen Leistungsfähigkeit positiv.

Monitoring wird bereits in verschiedenen Lebensbereichen eingesetzt. Dem Monitoring von Gesundheitsdaten kommt dabei in den letzten Jahren eine immer bedeutendere Rolle zu. In Bezug auf die körperliche Leistungsfähigkeit ermöglicht ein systematisches und kontinuierliches Monitoring die aktuelle Situation und das Niveau der motorischen Leistungsfähigkeit zu erfassen, aber auch Veränderungen und Entwicklungen zu erkennen und Muster zu identifizieren, auf deren Grundlage weitere Strategien und Maßnahmen zur Förderung abgeleitet werden. Um das Niveau der körperlichen Leistungsfähigkeit einer Person zu beurteilen, werden sportmotorische Testaufgaben durchgeführt, die das latente Konstrukt der körperlichen Leistungsfähigkeit auf der Produktebene sichtbar und messbar machen.

Allerdings ist eine große Menge an Daten erforderlich, die mit standardisierten Testbatterien und über einen langen Zeitraum erfasst wurden, um evidenzbasierte Informationen zu erarbeiten und praktische Erkenntnisse für die Bevölkerung abzuleiten. In der aktuellen Forschung zur körperlichen Leistungsfähigkeit ist dies ein zentrales Problem, obwohl der Open Data Ansatz auch in der Sportwissenschaft zunehmend an Bedeutung gewinnt und verschiedene Möglichkeiten für ein datengetriebenes und valides Monitoring bieten würde.

Vor diesem Hintergrund ist das Ziel der Dissertation, durch den Ansatz des Datenpoolings große Datenmengen aus verschiedenen Datensätzen zusammenzuführen und so die aktuelle Situation, Trends und Veränderungen der körperlichen Leistungsfähigkeit von Kindern zu untersuchen. Die Datensätze werden dabei datengetrieben im Sinne eines explorativen Vorgehens analysiert.

Diese kumulative Dissertation besteht aus vier wissenschaftlichen Artikeln und zusätzlich aus einem Best-Practice Beispiel. Um einen Überblick über den aktuellen Forschungsstand zu Trends der körperlichen Leistungsfähigkeit von Kindern zu bieten, wurde ein Review von epidemiologischen Studien durchgeführt. Auf Grundlage der Erkenntnisse wurden die Möglichkeiten des Datenpoolings zur Untersuchung von Trends der körperlichen Leistungsfähigkeit und Lösung methodischer Probleme diskutiert. Die folgenden wissenschaftlichen Artikel basieren folglich auf zusammengeführten Datensätzen und wurden zum einen mit einer Varianzanalyse (ANCOVA), aber auch mit einem komplexen gemischten Modell (Linear Mixed Model) untersucht. Dabei wurde insbesondere die COVID-19 Pandemie, als potentieller Einflussfaktor berücksichtigt. Die Ergebnisse wurden für die verschiedenen Fähigkeiten der körperlichen Fitness getrennt berichtet und weitere Variablen und deren Einfluss auf die körperliche Leistungsfähigkeit diskutiert. Mit dem Fitness-Barometer haben wir diese evidenzbasierten Erkenntnisse in die Praxis umgesetzt.

Da es international kaum Studien mit einer angemessenen Stichprobengröße und kontinuierlicher, standardisierter Erfassung der körperlichen Leistungsfähigkeit gibt, werden die Möglichkeiten, die das Datenpooling dagegen bietet, ausführlich diskutiert.

Die körperliche Leistungsfähigkeit von Kindern ist international insgesamt rückläufig, allerdings zeigt sich für die letzten Jahre eine Stagnation auf niedrigem Niveau. Die Ergebnisse variieren für die einzelnen Fähigkeiten. Für die Ausdauer und Kraft zeigen sich die meisten Veränderungen. Mit Beginn der COVID-19-Pandemie veränderte sich der Trends negativ. Er wird dabei aber zusätzlich durch andere Variablen, wie beispielsweise die Lebensumwelt oder das Niveau der körperlichen Leistungsfähigkeit vor der Pandemie, beeinflusst.

Aus den Ergebnissen zeigt sich, dass eine internationale Standardisierung der theoretischen Konstrukte und verwendeten Testbatterien zwingend erforderlich ist um das Datenpooling verschiedener Datensätze effektiver zu nutzen und zusätzliche Vergleichbarkeit zu gewährleisten. Datengestützte Analysen sind jedoch ein angemessenes methodisches Vorgehen, um Trends, Muster und Veränderungen der körperlichen Leistungsfähigkeit von Kindern zu analysieren und identifizieren. Um dieses evidenzbasierte Monitoring in die Praxis umzusetzen, sollten die Ergebnisse den Entscheidungsträgern und der Öffentlichkeit leicht verständlich präsentiert und praktische Umsetzungen vermittelt werden.

Aufgrund der Stagnation auf niedrigem Niveau und der Tatsache, dass frühere Kindergenerationen fitter waren als heutige, wirken sich selbst kleine Verluste auf die langfristige Entwicklung der körperlichen Leistungsfähigkeit aus. Ein standardisiertes und kontinuierliches Monitoring auf der Grundlage zusammengeführter Datensätze ermöglicht die umfassende Beurteilung des aktuellen Niveaus der körperlichen Leistungsfähigkeit und valide Identifikation von Trends und Veränderungen. Auf dieser Grundlage können evidenzbasierte Entscheidungen und zielgerichtete Maßnahmen und Programme zur Förderung der körperlichen Leistungsfähigkeit implementiert werden.

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Preface

Parts of this work have been published or submitted for publication. The following chapters can be read independently from each other:

CHAPTER 2: Eberhardt, T.*, Niessner, C.*, Oriwol, D., Buchal, L., Worth, A. & Bös, K. (2020). Secular Trends in Physical Fitness of Children and Adolescents: A Review of Large-Scale Epidemiological Studies Published after 2006. *International Journal of Environmental Research and Public Health*, *17*(16), 5671. https://doi.org/10.3390/ijerph17165671

CHAPTER 3: Eberhardt, T., Keller, K., Zimmermann, H., Schlenker, L., Bös, K. & Niessner, C. (submitted). The Potential of Data Pooling with Open Data Infrastructures in Motor Performance Research-A Discussion Based on the Example of MORE data. *German Journal of Exercise and Sport Research.*

CHAPTER 4: Eberhardt, T., Bös, K. & Niessner, C. (2022). Changes in Physical Fitness during the COVID-19 Pandemic in German Children. *International Journal of Environmental Research and Public Health*, *19*(15). https://doi.org/10.3390/ijerph19159504

CHAPTER 5: Eberhardt, T., Bös, K., Woll, A., Kliegl, R. & Niessner, C. (submitted). Secular Trends of Children´s Physical Fitness and COVID-Pandemic Impact for Years 2012 to 2022. *Sports Medicine – Open.*

* Authors contributed equally to this work.

CHAPTER 1

General Introduction

The aim of this dissertation is to investigate the current situation, trends and changes in children´s physical fitness with a data-driven monitoring.

Physical fitness is one of the fundamental resources for an active lifestyle and therefore of great importance for a healthy development in childhood and adolescence and throughout life (Gallahue et al., 2019). An adequate level of physical fitness enables children to be physically active, develop specific competencies and thus to prevent negative health outcomes (Bouchard et al., 2012; Jaakkola et al., 2016; Ortega et al., 2008; Robinson et al., 2015; Ruiz et al., 2009). Several studies emphasise the relationship between physical fitness and cardiometabolic disease, and reduced disability, even later in life (García-Hermoso et al., 2022; Henriksson et al., 2021). Similarly, physical fitness is associated with a lower risk of obesity and with cognitive and psychological benefits (Cadenas-Sanchez et al., 2021; Gu et al., 2019; Rodrigues et al., 2013; Smith et al., 2014). Knowing that the determinants of physical fitness have a moderate stability across the lifespan and given the link to the health-related focus, the need of a fundamental development of physical fitness in childhood is even more critical (Fraser et al., 2021).

To assess trends in the levels of physical fitness, monitoring and surveillance provides analysis of the physical fitness levels of the youth population and interpretation of its course. It enables evidence-based findings to be reported and further potentials and challenges to be identified. Population health monitoring has become more focus in the recent years due to the higher quality of information it provides (Verschuuren & Van Oers, 2020). Decision-making, policy-making and planning of further interventions and strategies are based on a comprehensive and broad screening of research sources such as health data (Brownson et al., 2009). Population health monitoring has different stages of development and could be described by an information pyramid. At the top of the pyramid is wisdom, which outlines the ability to make decisions based on the evidence (Ackoff, 1989; Verschuuren & Van Oers, 2020). With regard to physical fitness, some countries and initiatives have developed systematic monitoring and derive action from the findings (Brazo-Sayavera et al., 2024; Eberhardt et al., 2021; Ortega et al., 2023). For example, the Fitness Barometer is implemented in a German federal state and published annually (Eberhardt et al., 2021). The analysed questions and results demonstrate how physical fitness monitoring could look and how the information pyramid could be realized within population health monitoring. Recent research has identified several challenges and barriers to the lack of physical fitness monitoring (Brazo-Sayavera et al., 2024). Among others, the collection and processing of data is one of them. Data on physical fitness are limited and lack standardisation and comparability (Brazo-Sayavera et al., 2024; Lang et al., 2023; Lopes et al., 2020). However, data are the basis of the process of monitoring and lead to evidence-based decision-making.

The development of digital transformation and datafication is significantly increasing the extent to which data is used in research. In various fields, the trend towards collection, storing, and processing of data grew and open up the high availability of data. This data-driven approach is also driving public health and sports science (Brownson et al., 2009; Ding, 2019). It emphasises the use of large datasets for relevant questions of physical fitness in context of epidemiology as analyses of population health (Salathé et al., 2012). This increases the relevance for research and evidence of health monitoring for decision making and information of population (Verschuuren & Van Oers, 2020). Through the use of data-driven monitoring, patterns of trends and changes in physical fitness are revealed and help to generate new hypotheses. To address the need for large amounts of appropriate data, data pooling is a used method in physical fitness research. It refers to the merging of existing data to create a larger and more representative dataset with sufficiently powered samples (Eberhardt et al., 2021). This enables data-driven statements on global trends and cross-cultural comparisons of physical fitness levels in children. The spread of the COVID-19 pandemic has had a huge impact on children´s life and their opportunities to be physical active. Thereby, even more essential is a long-term monitoring on a solid and broad data base, so that changes can be identified and results can be compared with previous and subsequent findings (Lang et al., 2023; Lopes et al., 2020). Often, international studies that examine trends report them based on samples that are usually too small to provide representative evidence. There is no continuous monitoring, as only a few measurement points are used to derive trends or changes (Brazo-Sayavera et al., 2024; Lopes et al., 2020). In addition, a permanent and regular assessment of physical fitness in a large sample is difficult to implement due to limited resources and the amount of specific needs for implementation, especially in children.

Therefore, this dissertation aims to investigate the current situation, trends and changes in children´s physical fitness. The basis for the objectives is a test-diagnostic approach based on the ability-oriented concept of physical fitness (Bös, 1987; Bös & Mechling, 1983). Data pooling is used to provide data-driven and evidence-based monitoring, combining data of motor tests from populational cross-sectional cohort samples. This fills the gap of systematic, continuous, long-term, and standardised monitoring for further strategies and actions in physical fitness research of children.

Theoretical Background

In order to point out the consideration of physical fitness in relation to health, a theoretical model that also includes physical activity is used to guide for the purpose of this work. The model by Bouchard et al. (2012) requires a holistic approach and explains the complex relationship between physical activity, physical fitness and health. Physical activity as a subordinate term refers to "any bodily movement produced by muscles and resulting in energy expenditure" (Caspersen et al., 1985). Furthermore, there are different dimensions, domains, and time frames that divide physical activity (Jekauc et al., 2014). In addition, the WHO has based its health recommendations on the different levels of intensity: light, moderate, and vigorous (Bull et al., 2020). In contrast, physical fitness is defined as "a set of attributes that people have or achieve that relates to the ability to perform physical activity" (Caspersen et al., 1985). More specifically, the dimension of health-related fitness refers to those components that are influenced by a physically active lifestyle and are related to health. These components and traits are wide-ranging, including morphological, cardiorespiratory, muscular, motor, and metabolic ones (Bouchard et al., 1994). The definitions are well established in the field and the positive relationship between physical activity and health benefits is commonly evidenced (Bouchard et al., 2012, 2015; Bull et al., 2020; Pate, 1995). However, the realistic model is even more complex. Bouchard et al. (2012) state that physical fitness, and in particular health-related physical fitness with its different components and traits, is also part of the relationship. Figure 1 illustrates the complexity of the interactions between the three basic variables. With regular physical activity, components of physical fitness (i.e. cardiorespiratory endurance) and beneficial health aspects (i.e. decreasing blood pressure) increase. However, some of the health benefits of physical activity are obtained without any positive changes in physical fitness and are therefore independent from it. More specifically, the pathways are not necessarily causal, as being healthier tends to lead to being more active. Similarly, fitter individuals modify their level of physical activity, so fitter ones tend to be the most active. Other factors such as the social and physical environment, lifestyle behaviour, and personal attributes, as well as genetics, are also part of the overall model, and are influencing and determining the basic variables of physical activity, physical fitness and health.

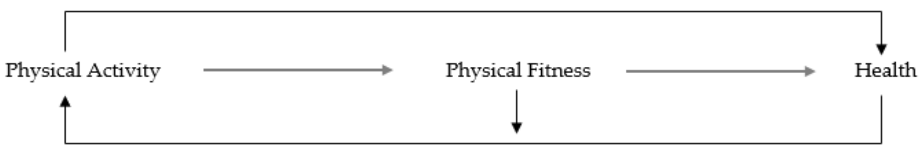

Figure 1. Relationship between Physical Activity, Physical Fitness and Health (Bouchard et al., 2012, p.17)

With the introduction of the theoretical model of Bouchard et al. (2012), the importance of physical fitness for health and its embedding and distinction in a construct with physical activity and health is obvious. Physical fitness as a multifaceted construct through all the functions and processes involved, is considered as "the most important health marker" (Ortega et al., 2008). The foundation for these reciprocal relationships and associations is an adequate motor development and physical fitness levels already in childhood and adolescence.

In their conceptual model, Stodden et al. (2008) describe the dynamic processes and relationships between health-related variables across developmental time in childhood that lead to engagement in physical activity. Within the similar main variables, Stodden´s model specifies how the determination of physical activity and its implications within the model of Bouchard et al. (2012) are developed in childhood. At the center of the model, motor competence plays a significant role in being physically active. Motor competence is “an individual’s degree of proficiency in performing a wide range of motor skills as well as the mechanisms underlying this performance” (Bardid, 2019). In a more practical specification it refers to the use of one´s personal given motor potential resulting in context-specific and adaptive movements. Fundamental movement skills play a critical role in this, as they are considered as the foundation of motor competence and develop essential movement patterns (Gallahue et al., 2019; Logan et al., 2018). The model points out the importance and essentiality of knowing how to move as a foundation for being physically active. This relationship between motor competence and physical activity strengthens over developmental time, either encouraging or discouraging someone to be physically active, and persist into adulthood. Higher motor competence provides greater potential in movement to engage in physical activity, sports, and games, particularly through positive perceived motor competence (Stodden et al., 2008). Inversely, physical activity promotes the development of motor competence through confirming experiences, particularly in early childhood (Clark, 2002; Gallahue et al., 2019; Scheid, 2009; Stodden et al., 2008). In addition, other health-related factors mediate the dynamic relationship between motor competence and physical activity (Stodden et al., 2008; Utesch et al., 2019). Physical fitness, as defined by Caspersen et al. (1985) and also included in the model of Bouchard et al. (2012), is positively associated with motor competence (Cattuzzo et al., 2016; Utesch et al., 2019). Although, physical fitness and motor competence are theoretically distinct constructs, they are directly and indirectly linked and empirically coincided (Utesch, Dreiskämper, Strauss, et al., 2018; Utesch et al., 2019). The relationship is reciprocal and dynamically strengthens across development in childhood (Utesch et al., 2019). To perform goal-directed movement patterns and fundamental movement skills, different dimensions of physical fitness and activation of the neuromuscular system are required. An adequate number of repetitions is necessary to master the movement, which could positively influence endurance. Thus, the development of motor competence is related to cardiorespiratory fitness and muscular strength during childhood and adolescence (Cattuzzo et al., 2016; Utesch et al., 2019, p. 201). In addition, an adequate level of motor competence encourages children to be more physically active and thereby fosters their physical fitness at the same time. On the other hand, children with a low level of physical fitness, will not be able to persist in physical activities, thus limiting the further development of motor competence (Stodden et al., 2008). This construct is varying individually. The level and role of physical fitness differs not only between individuals, but also within over developmental phases. However, the conceptual model of Stodden et al. (2008) describes the underlying mechanisms in motor development. In childhood, an adequate level of motor competence is the critical variable in the synergistic relationship with physical activity. As mediating variable physical fitness is also relating within this dynamic process throughout childhood. In the global picture of physical activity, physical fitness and health, both models help to understand the relationships and associations. In addition, it points out, that an active and healthy lifestyle even starts in childhood with an adequate level of physical fitness mediating the other variables and showing stability across the lifespan.

There are numerous terms that are often used synonymously to describe physical fitness in children and there exist various definitions and theoretical models of their reciprocal interactions. Common to all is the concept of a complex, multidimensional construct with different factors and mediators (Logan et al., 2018; Stodden et al., 2008). Empirically, there is considerable overlap between the different theoretical considerations (Utesch et al., 2019). However, in order to investigate these relationships and provide more evidence, the challenge is to assess the variables appropriately and within a theoretical construct.

In Germany, the most commonly published construct behind the assessment of physical fitness is the ability-oriented approach by Bös and Mechling (1983). In this context, motor competence can be defined as the proficiency to use the individual development of movement patterns and dimensions to realize and perform physical fitness. Bös and Mechling (1983) processed the construct of physical fitness as an analytical, structural model to assess the level of performance. The central underlying assumption implies, that there is an internal latent process level and an obvious manifest observation level that could be assessed with test items on a product level. From an external perspective, the aim is to describe apparent abilities and actions of movement concretely. From an internal perspective, the aim is to define a fundamental systematic and causal representation that underlies them (Bös & Mechling, 1983). For this reason, Bös and Mechling (1983) established a dimensional structure of motor abilities in which energetically-determined and information-oriented dispositions are named motor abilities in conclusion. They enable the successful execution of movements and build the basis for the development of more specific skills and movement patterns. Based on a structural model for explaining performance in sport specific movements, on a first level motor abilities were differentiated into conditional (energetically-determined) and coordinative (information-oriented) abilities. These complexes are further distinguished into five the fundamental abilities: endurance, strength, speed, coordination and flexibility. Endurance and strength are clearly assigned to the energetic pole and coordination to the information-oriented pole. Speed and flexibility, however, cannot be clearly assigned to one or the other. Speed is considered to be a mixed conditional and coordinative determined ability, whereas flexibility plays a special role within the classification, because its predominantly anatomically determined by the passive systems (Bös & Mechling, 1983). On a third level, the energetically determined motor abilities are further differentiated according to the duration, intensity or agility of the performance (see Figure 2). The information-oriented abilities are further distinguished according to the type of sensory regulation as well as according to the requirements of the movement. In general, the interaction of conditional and coordinative abilities is crucial for the development of movement activity, the accomplishment of movement tasks, and the acquisition of fundamental skills, e.g. running, and context-specific and complex skills, e.g. dribbling in handball (Bös, 2017; Worth et al., 2022).

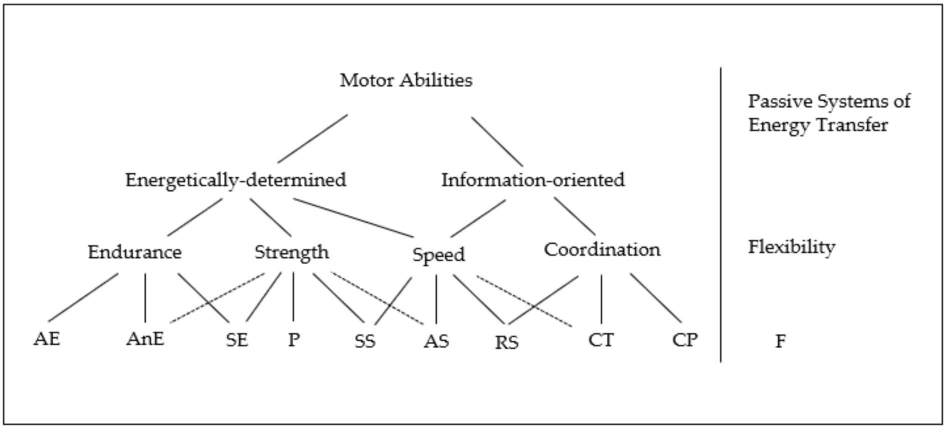

Figure 2. Differentiation of motor abilities in the ability-oriented approach (modified of Bös, 1987)

Within their model, Bös and Mechling (1983) were able to empirically confirm the theoretical assumptions of dimensions of physical fitness. The ten motor abilities are stated as the observable categories of description of a general physical fitness.

This dissertation and included papers are guided by the previously described theories. They formed the foundation of the assessment of physical fitness due to its essential role with physical activity and health and in particular motor competence in childhood. In Germany, the most common approach is the presented ability-oriented Bös and Mechling (1983), which categorizes physical fitness into five main dimensions. In addition, there exist numerous measurements tools for assessing physical fitness based on different approaches and theories. The selection of the appropriate one is highly dependent on the field of implementation and the purpose of the assessment (Bardid et al., 2019; Burton & Miller, 1998; Utesch et al., 2019). Beginning in 2006, an ad hoc group had to develop a standardized and uniform test battery to continuously assess the level of physical fitness of children and adolescents nationwide. The purpose was to base political decisions based on solid data (Bös et al., 2009). As the German Motor Test was used to assess the physical fitness of children in the included papers, a brief overview is provided.

In order to measure an individual´s level of performance on the differentiated abilities, test items are conducted on a product level and combined into test profiles or batteries. However, the construction of test batteries must also consider personal, task-specific, and situational conditions and structures. In a three-dimensional taxonomy, Bös (1987) distinguished between the dimensions: structure of abilities, task structure and environment of the action to capture the realization of motor abilities within sports motor tests. From a practical point of view, some of the cells within the taxonomy are less important and therefore a gradual reduction has been made. For tests targeting a general rather than a sports-specific assessment, the environment of the action could be neglected because the external conditions of test implementation are consistent. As a result, Bös (1987) identifies 12 basic types of test items. In summary, the construction of a general assessment of physical fitness must be based on theory and methodological standards, as well as incorporating practice and a clear reference to the implementation (Bös, 1987). Based on these test theoretical considerations for test construction, further considerations were made in the development of the GMT. For the quantification of motor abilities within a general physical fitness test, a final taxonomy of test items by structure of abilities and task structure was reported (Table 1) (Bös et al., 2009). In addition, body constitution is complemented within the passive systems of energy transfer when assessing physical fitness.

Table 1. Taxonomy of test items (modified of Bös et al, 2009)

Task Structure		*Motor Abilities*							*Passive Systems of Energy Transfer*
		Endurance	*Strength*		*Speed*	*Coordination*		*Flexibility*
		AE	*SE*	*P*	*AS*	*CT*	*CP*	*F*
Locomotor movements	*Walking, Running Jumping*							
Movements of Body Parts	*Upper Extremities*							

AE = Aerobic Endurance; SE = Strength Endurance; P = Power; AS = Action Speed; CT = Coordination under Time Pressure; CP = Coordination under Pressure of Precision; F = Flexibility

In the final selection, the GMT was published with eight test items (Figure 3), which are in detail described within the manual and completely cover the motor abilities of physical fitness (Bös et al., 2009). In order to make the manual more practical for the user, it has been revised three times recently published (Bös et al., 2023). An English version is also available (Bös et al., 2021).

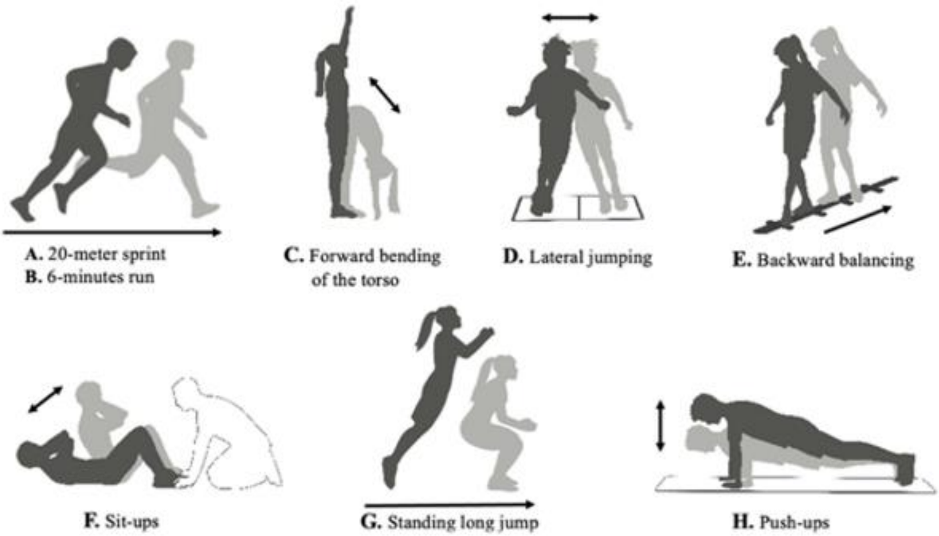

Figure 3. Test items of the German Motor Test (Drozdowska et al., 2021)

The GMT was developed specifically for standardized implementation in a practical setting and the authors considered the specific circumstances and requirements in this field. The test items have been thoroughly selected for their economy and practicability. They are easy to conduct in a sports hall and do not require any instrumental measurement tools. For the user, the test items are easy to understand and explain due to their wide distribution. In addition, the age range allows a standardised measurement without any age-specific adjustments or divergent organisation. Numerous concepts have already been developed and published for the various fields of implementation, e.g. for schools, the integration into the educational curriculum has been worked out and a complete lesson unit has been developed for the implementation of the GMT (Eberhardt et al., 2023). The GMT was designed to serve as a standardized tool to assess the level of physical fitness of children and adolescents in a comprehensive and multidisciplinary. As such, it allows to systematically assess population-based data of children´s physical fitness and to investigate large and heterogeneous samples. The resulting data provide information on the strengths and weaknesses of physical fitness with its specific abilities, but also within different groups. Through regular and consistent implementation, the motor development of children can be analysed in a longitudinal design, but also between different cohorts. Thus, changes and trends in the population can be examined and a monitoring of physical fitness is given based on a standardised and valid test battery.

Monitoring is used in various fields, settings, and contexts and refers to a continuous surveillance through systematic assessment and processing of data (Kloe, 2021; Verschuuren & Van Oers, 2019). Focusing on a monitoring of public health themes, it refers more specifically to regular and institutionalized dissemination and information on health-related issues and determinants. As such, physical fitness monitoring is one part of the global concept and aims to inform relevant decision makers and society about within a topical focus (Verschuuren & Van Oers, 2019). Ideally, monitoring comprises available scientific evidence and practical considerations such as population characteristics and resources. Therefore, evidence-based public health is a process of balancing knowledge and information (Brownson et al., 2009).

An often described model is the information pyramid (Figure 4), which is also named Data-Information-Knowledge-Wisdom hierarchy (DIKW) (Ackoff, 1989). Data form the base of the pyramid and the evidence. Applying this to public-health and specifically to physical fitness research, quantitative data on performances in tests of physical fitness are one possible foundation. Data must then be transformed into information through analyses and interpretation using appropriate methods. This step requires a specific selection of sources and processes with regard to the objectives of the monitoring, but is also achieved through objective and subjective interpretation of the findings. The transition to the third level, knowledge, is therefore fluid. The information obtained is transformed into knowledge through the contextualisation of patterns. Findings are comprehensively reported and placed in broader and relevant perspectives. Additional evidence from different fields is used to provide possible explanations for the observed results and to discuss perspectives of suitable approaches. At the top of the informed pyramid wisdom translates knowledge into evidence-based and well-informed decisions (Verschuuren & Van Oers, 2019, 2020).

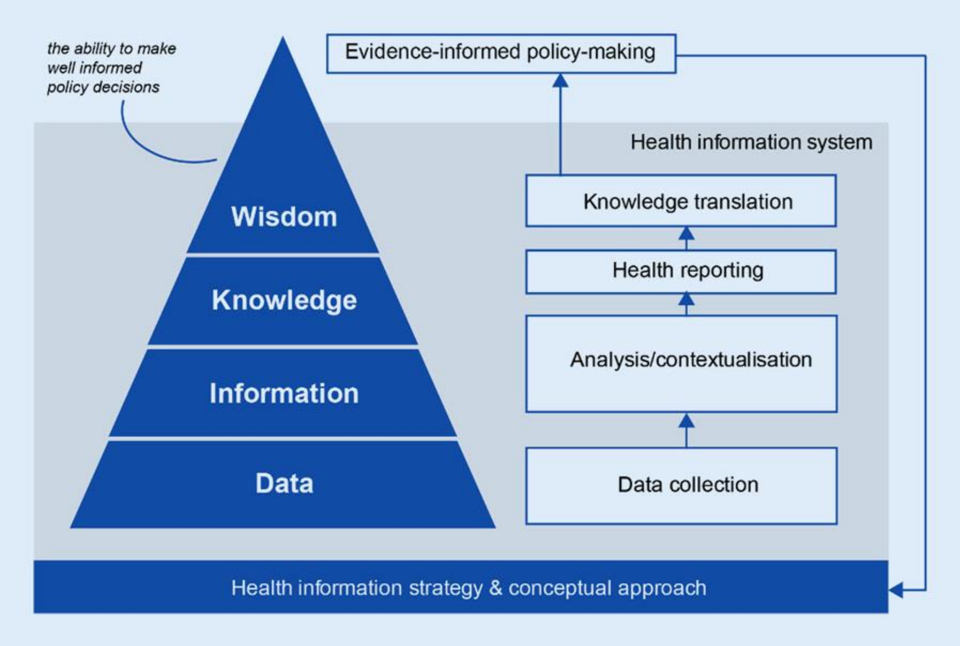

Figure 4. The Informed Pyramid (Verschuuren & Van Oers, 2020, p. 1135)

In this way, the informed pyramid is a processed structure, it is the strategy behind the development of population monitoring. Influencing variables and factors are considered from the beginning, not only when collecting data, but also when analysing and transforming it. This also includes the selection of an appropriate format of publishing tailored to the target group (Brownson et al., 2009; Verschuuren & Van Oers, 2020). For the constitution of broad health information system, a set of resources, actors, activities, and outputs should be involved within the process. This provides a high degree of social relevance and an integrative, comprehensive and structured approach with the using consistently collected data. In practice, however, there are often technical and economic barriers. Data-driven approaches and technologies, offer solutions to utilize population health monitoring even more efficiently generating a sufficient amount of data (OECD, 2019; Verschuuren & Van Oers, 2020).

Aims and structure

Based on these theoretical assumptions, this dissertation aims to investigate the current situation of children´s physical fitness and its trends and changes over time with regard to a population health monitoring. The objectives were analysed with a data-driven approach, which means that the process of evidence is made exploratory to gather scientifically interesting patterns and trends within the cross-sectional data. This is a cumulative dissertation, consisting of four papers and a best practice example. First, a review was conducted to survey the current state of research on the topic. Second, we aimed to address the identified challenges and research gaps by pooling existing data on physical fitness, collected with the GMT and further processed with the MO|RE data repository. This resulted in a methodological discussion paper on the potential of data pooling for physical fitness research. Building on this, the following papers are data-driven empirical analyses and evidence-based scientific monitoring. One of these papers comprehensively analysed secular trends in children´s physical fitness in relation to the potential impact of the COVID19-pandemic. The other one focused on the change in physical fitness in a specific sample due to the unpredictable event. In addition, a best practice example of an implemented monitoring instrument in children´s physical fitness is given to demonstrate how evidence-based findings are of practical value in population health monitoring. The dissertation ends with a general discussion of the main findings and theoretical and methodological considerations for the future are outlined. Strengths and limitations are discussed followed by the conclusions of this dissertation.

Figure 5 illustrates the structure of this work with the included papers and method of data pooling that results in further analyses. The introduction and main results of the papers are described in more detail below. In addition, their convergence within this dissertation is explained by reporting conclusions and feasible research gaps.

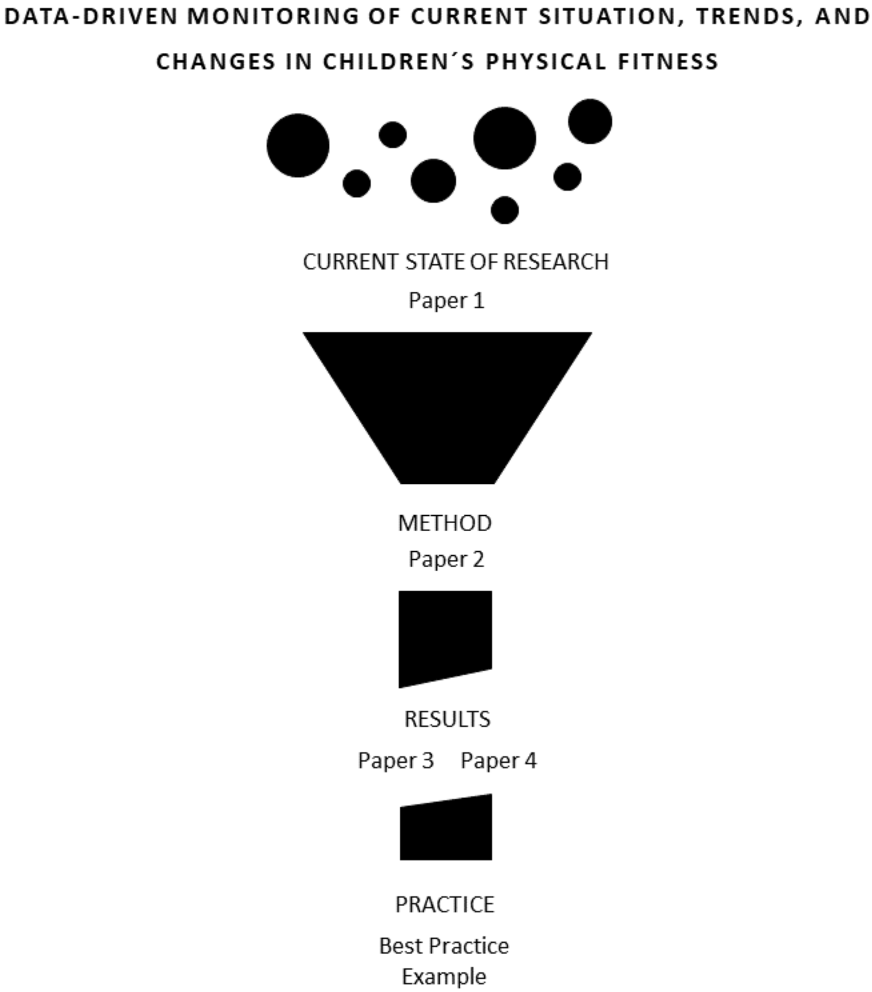

Figure 5. Structure of the dissertation (own illustration)

Paper 1: Secular Trends in Physical Fitness of Children and Adolescents: A Review of Large- Scale Epidemiological Studies Published after 2006

Population-based studies rarely report trends in physical fitness in children and adolescents, although monitoring of them is crucial because of the enormous impact of physical fitness on health (Gallahue et al., 2019; Tomkinson et al., 2018). Although some studies of trends exist, they comprise only certain abilities of physical fitness or use limited measurement points (Hardy et al., 2018). The most recent reviews report secular trends in physical fitness up to the beginning of the millennium, but not much beyond that (Tomkinson & Olds, 2007b). In addition, there coexist a number of different test batteries, test items and also theoretical constructs on which they are based (Gerlach et al., 2017; Scheuer et al., 2019). To overcome the lack of a comprehensive overview, we first conducted a review of large-scale epidemiological studies published after 2006 on all dimensions of physical fitness (Lopes et al., 2020). The first publication of this dissertation (Eberhardt et al., 2020) therefore addresses the decisive question:

What is the current state of research on trends in physical fitness of children and adolescents?

The relevant results of the included studies were divided into specific subsamples by test items and sex and categorized into increase, stagnation, and decrease. We analyzed the secular trends separately for the five different abilities of physical fitness: endurance, strength, speed, flexibility, and coordination. The results showed varying trends in the specific dimensions. In addition, the difficulty of comparing the results due to heterogeneous methods of assessing physical fitness, different sample sizes and statistical analyses is evident. Also, the time periods between the measurement points and their amounts are sufficiently different. Based on these findings, we conclude future implications for monitoring in physical fitness and confirm the needs of previous research (Lopes et al., 2020; Pate et al., 2012). Trends in children´s physical fitness need to be systematically determined with targeted study protocols and standardized assessment tools. Measurement points should be continuous, at regular intervals, and over a long period of time in order to derive trends on a solid basis. With an implicit monitoring, we assume the findings are sustainable in terms of planned interventions and programs. Furthermore, this would help to exploit the potential for benefits of physical fitness for health and an active lifestyle (Lang et al., 2018). However, this requires significant resources and effort to generate data.

Paper 2: The Potential of Data Pooling with Open Data Infrastructures in Motor Performance Research - A Discussion Based on the Example of MORE data

The importance of data increases with the demands and requirements of monitoring in physical fitness. In line with this, data of physical fitness already exists in numerous national and international projects spanning several decades (Joensuu et al., 2024; Lang et al., 2023; Lopes et al., 2020). They represent an objective and reliable source and evidence base with enormous potential for further in-depth analyses. At the same time, the Open Data approach is becoming more public and common across all scientific disciplines. Researches get used to accessing comprehensive and various data, that contribute significantly to the understanding of complex research questions (Munafò et al., 2017; UNESCO Recommendation on Open Science, 2021; Utesch et al., 2017). The increasing focus on data-driven approaches helps to overcome existing problems and limitations in research in a more exploratory way (Maass et al., 2018). Especially, when large datasets are needed, such as for physical fitness monitoring, data-driven approaches offer opportunities but also face specific challenges. The second publication of this dissertation (Eberhardt et al., submitted) therefore addresses the question using the example of a discipline specific repository:

How can we use MO|RE data for further research in physical fitness?

By introducing the repository MO|RE data, we discuss the specific needs and requirements of physical fitness data. At the same time, we show how these are implemented in MO|RE data. In the repository, data providers can upload their data on physical fitness measures as a dataset and thus store and publish them. Mechanisms have been implemented to ensure the quality of the physical fitness data, and to guarantee the consistency of dataset variables across different published datasets. To reuse published datasets, structured and transparent information within the metadata is queried. With an assigned Digital Object Identifier (DOI) as a unique reference, datasets and their owners can be cited like other scientific articles. We conclude, that this allows a fair and transparent re-use of data. MO|RE data provides access to a wide range of data from different sources and therefore serves as technical solution to comply with data-driven monitoring in physical fitness. In fact, a data user can search for different characteristic samples and export the dataset for re-use. This systematic pooling and use of various datasets as one big dataset provide new opportunities for reporting trends in physical fitness. Research needs for systematic, long-term and continuous monitoring can be met. Collaborative and fair use of data could provide a comprehensive global picture of current levels, changes, and trends in children's physical fitness (Eberhardt et al., 2020; Lopes et al., 2020). Data pooling with regard to monitoring children´s physical fitness brings together various samples and thus overcomes existing challenges in examining trends. It allows for more exploratory analyses that would otherwise be limited due to insufficient sample sizes.

Paper 3: Changes in Physical Fitness during the COVID-19 Pandemic in German Children

With the onset of the COVID19-pandemic, an unexpected factor emerged that could potentially affect physical fitness through changes in daily life. In Germany, the COVID19-pandemic began in January 2020 and was accompanied by various restrictions that also affected organized sports facilities and opportunities of being physically active (Schilling et al., 2021). There are already some studies that have investigated the effects of the COVID19-pandemic not only on physical activity but also on physical fitness (Chambonnière et al., 2021; Jarnig et al., 2021; Wunsch et al., 2022). However, due to the sudden occurrence, there are obvious issues of unpredictable measurements and missing data. Sufficient short- and long-term data within the different abilities of physical fitness and multiple measurement points are lacking, but are needed as a sufficient basis for analysing changes. Given the enormous importance for the current and future development of an active and healthy lifestyle, it is crucial to provide evidence of the effects and consequences of the COVID19-pandemic on children´s physical fitness. In this case, we could benefit from data pooling and provide direct short-term data-driven evidence. By analysing detailed and specific data, we aim to identify targeted effects and report differences within dimensions for a specific sample. The third publication of this dissertation (Eberhardt et al., 2022) therefore addresses the question:

How did COVID19-pandemic affect physical fitness of children?

To overcome the challenges in directly analysing COVID19-pandemic consequences, we benefited from the annual measurement of physical fitness within a community that regularly conducted the GMT within specific age groups. By pooling the various independent samples from different years, we generated a large dataset of cross-sectional cohorts. Overall, there was no evidence of a negative effect of the COVID19-pandemic on physical fitness, but the findings differed between the specific dimensions. Alternative exercise options may mitigate the effects. The particular community is also an example of how long-term engagement helps to establish an above-average level of physical fitness. This makes a difference when overcoming time of crisis.

Paper 4: Secular Trends of Children´s Physical Fitness and COVID-Pandemic Impact for Years 2012 to 2022

The previous paper showed how a data-driven approach with data pooling can be used to monitor physical fitness on a short-term basis when specific circumstances arise. However, the main focus of data pooling and data-driven analysis are to provide evidence of trends and changes over a longer period of time. As the current state of research indicates a “stagnation on a low level” in children´s physical fitness, but also lack of more detailed findings, evidence suggests to identify more specific trends and expand the objectives (Eberhardt et al., 2020). However, this requires homogeneity and standardization, which are difficult to achieve in an individual study for a variety of reasons. By pooling of existing data, we took the opportunity to fill the research gap of further much needed evidence based on standardized assessment with the same test items for the different dimensions of physical fitness over a long period of time. In order to deal with the complex data structure that results from pooling such a large amount of data, we used a statistical method for this analysis that gives us many ways to derive precisely estimated secular trends. However, the overall aim of contextualize the findings adequate for population health monitoring was still present. The fourth publication of this dissertation (Eberhardt et al., submitted) therefore addresses the question:

What are current secular trends in children´s physical fitness?

A population-based ad hoc sample of cross-sectional cohorts was pooled from the individual samples. When analysing trends over the past decade, the COVID19 pandemic could not be ignored and we generated a model for trends integrating COVID-19 pandemic as a quasi-experiment. This results in evidence of relatively small trends in most of the test items or even no significant trend was found It also supports the weakening of decline in previous years

(Eberhardt et al., 2020; Masanovic et al., 2020; Tomkinson & Olds, 2007b). The effects of COVID19-pandemic are specific and vary between the different dimensions of physical fitness. For some test items, a negative change in the previous trends was evident, indicating that the secular trend was changed by COVID19-pandemic. In this way, the paper illustrates well, that even if complex analyses are necessary for scientifically adequate evidence, findings for practical statements are feasible. The fundamental purpose for research and practice is to examine whether the findings are just a COVID dip, or a significant bend in the trend.

A Best Practice Example: The Fitness Barometer

In order to translate the evidence-based findings into knowledge and to make scientific surveillance a practical value, it is essential to implement instruments that provide information in a comprehensible but topical manner. Evidence-based public health requires contextualization and processing to make findings applicable to decision-makers and practitioners, who derives actions from them. The findings and format of The Fitness Barometer demonstrate how monitoring of physical fitness could be done in practice. It deliberately avoids a detailed scientific description of the individual values and results, instead showing how they are made accessible, what questions are addressed in the example and how they are prepared for publication for the general public. Examples of practical recommendations for action that have been derived from the scientific processing of the data are given.

CHAPTER 2

State of Research in Secular Trends in Physical Fitness of Children and Adolescents

Slightly modified version of the published paper:

Eberhardt, T.*, Niessner, C.*, Oriwol, D., Buchal, L., Worth, A. & Bös, K. (2020). Secular Trends in Physical Fitness of Children and Adolescents: A Review of Large-Scale Epidemiological Studies Published after 2006. International Journal of Environmental Research and Public Health, 17(16). https://doi.org/10.3390/ijerph17165671

*Authors contributed equally to this work

Abstract

Physical fitness (PF) of children and adolescents is an important resource for their future health. Population-based studies, however, rarely report secular changes of PF, although monitoring of these is crucial to deriving information for adequate interventions. This review aims to report trends in PF of children and adolescents. A literature search was conducted in PubMed in July 2019. Cohort studies published in English allowing statements to be made on trends in PF by comparing youth between the ages of four and 18 years were included. The review identified 24 studies from 16 countries meeting the inclusion criteria, with an overall sample size of more than 860,000 children and adolescents. Through a standardized quality assessment tool, we classified two studies as strong, 21 as moderate, and only one as weak. We analysed specific secular trends separately for the five different dimensions: endurance, strength, speed, flexibility, and coordination. The majority of studies report a decline of PF over time; however, a few studies report conflicting results. Performance in endurance, strength, and flexibility decreased over time, whereas there was no consistent trend reported for speed and coordination. Overall, there is no international standard on examining and reporting changes or secular trends in PF of children and adolescents, and comparability of studies is limited due to heterogeneous conditions of conducting and analysing PF tests. Consequently, standardized and consistent international monitoring should be implemented.

Introduction

Monitoring of physical fitness (PF) in youth is important, because PF is known as one of the most relevant resources for health (Dwyer et al., 2009; Hamer et al., 2020; Ortega et al., 2008; Ruiz et al., 2009) and is regarded as one of the foundations of an active lifestyle (Stodden et al., 2008). Childhood is a critical period for the development of PF as it lays the foundation for later PF. Young children acquire a wide range of locomotor and object control skills that enable them to learn adaptive, skilled actions and to adjust them flexibly in different contexts. PF is the base on which children can build more specific motor skills or develop movement patterns. The development of motor performance either encourages or discourages an individual to engage in physical activity through limiting one's opportunities (Clark & Humphrey, 2002; Cliff et al., 2016; Jaakkola et al., 2016; Larsen et al., 2015; Lubans et al., 2010; Stodden et al., 2008). Various definitions of the term PF exist. In Germany, the most commonly used definition was published by Bös (1987). According to this definition, five main dimensions of PF can be distinguished: endurance, strength, speed, and coordination, with flexibility as an additional passive dimension (Lämmle et al., 2010). This definition is based on the concept of physical fitness by Caspersen, Powell, and Christenson (1985) and is the basis of this analysis.

In many parts of life, systematic monitoring is used to document changes in society and to describe their course over a certain period of time. Considering the high impact of PF on health in childhood and adolescence, it is crucial to examine how PF has changed over time in children and adolescents. Systematic monitoring of PF is thus needed to assess and design interventions and programs aiming to maintain or increase PF (Greier et al., 2019; Hanssen-Doose et al., 2021; Tomkinson et al., 2018; Tomkinson & Olds, 2007a).

The majority of large, international studies report the current status and development of PF on the basis of independent, aggregated datasets from differently composed cross-sectional samples. Only few studies exist that were designed to investigate secular trends in PF of children and adolescents with a sufficiently large sample size, an investigation period with several measuring points, and a uniform methodology over years. Unfortunately, population-based studies on trends in PF are rare due to the high time and financial burden needed for carrying out the PF tests (Tremblay et al., 2010). Reliable statements on the current status and on changes, such as secular trends, in PF of children and adolescents on population level are therefore rarely reported on a national and international level.

A few review studies reported decreases in PF levels in the last three decades. For example, a review by Bös (2003) analysed secular trends in PF from 1975 to 2000 in different countries using representative data of over 100,000 children and adolescents. A significant decline of PF of −10% was found for this period and results were particularly conspicuous for endurance and flexibility (Bös, 2003). An extension of this review to cover additional data published until 2006 confirmed these prior observations and additionally, revealed that the decline in PF was lower for children than for adolescents (Bös et al., 2008). A summary of international literature on aerobic and anaerobic performance of children and adolescents by Tomkinson (Tomkinson, 2007) included data from over 25 million children and adolescents aged 6–19 years from 27 different countries between 1958 and 2003 (Tomkinson, 2007; Tomkinson & Olds, 2007b). For aerobic performance as measured by different field running tests, the same trends were observed as in the review by Bös et al. (2008) namely, that aerobic performance declined at an average rate of −0.36% per year during this period (Tomkinson & Olds, 2007b). This decrease was particularly evident for aerobic performance after 1970, following a slight increase from 1958 until 1970 (Tomkinson & Olds, 2007a). The results for anaerobic performance were different. PF tests for strength and speed showed a general annual improvement of 0.03% (strength) and 0.04% (speed), particularly before 1985. After this period, changes stabilized or declined (Tomkinson, 2007).

To our knowledge, there is no review published after 2006 that includes data on secular trends in PF over all dimensions. Therefore, the aim of this review was to conduct a literature search on secular trends in PF of children and adolescents in large-scale epidemiological studies published since 2006. In addition, we aimed at considering a wide range of different dimensions of PF, including endurance, strength, speed, flexibility, and coordination. The different assessment periods, test procedures, and potential gender effects on PF secular trends were of particular interest. Based on current results of individual studies (Hanssen-Doose et al., 2021), we hypothesized that the evidence of the published studies on PF in children and adolescents reveals a stabilization on a rather low level and that the decline in PF is no longer as pronounced as noted in the reviews described above.

Material and Methods

This review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guidelines (Liberati et al., 2009). However, registration of this review to record the process using a database such as PROSPERO (International Prospective Register of Systematic Reviews) was not made. See Table S2 Review protocol for a detailed explanation of the methodological options of the researchers, as well as the sequence and procedures to be implemented in conducting this review.

Eligibility Criteria

Studies meeting the following inclusion criteria regarding the PICOS (participants, interventions, comparators, outcomes, and study design) approach (Liberati et al., 2009) were included in this review:

- Participants between the ages of four to 18 years;
- No intervention;

- Comparison with former measurement point(s);
- Statements of trends in the different dimensions of PF;
- Cohort studies with at least two different measurement points;
- Size of study population n > 100.

Only studies published in peer-reviewed journals and written in English were considered. Exclusion criteria were study populations characterized by a physical disease or conducted in a clinical setting, such as diabetes or preterm birth. Additionally, studies among participants with a competitive athletic background and studies analysing relations, effects, or influences of a specific variable such as sociodemographic status were excluded.

Search

The database PubMed was searched for original studies published between January 2006 and July 2019. The search was conducted in July 2019. The search term consisted of three specific sections, including related terms:

- Section 1—Study population: children OR adolescent* OR youth OR child OR Kinder OR Jugendliche;
- Section 2—Study design: cohort stud* OR Kohortenstudie* OR survey OR longitudinal OR trend* OR secular OR follow-up;
- Section 3—physical fitness: “Motor performance” OR “körperlicheLeistungsfähigkeit” OR “physical fitness” OR fitness.

Within the three specific sections, at least one term had to be met. The sections as a whole were connected with the AND operator. See Table S3 full research strategy for detailed documentation.

Study Selection

The search was conducted stepwise by two independent reviewers. The data were managed with Citavi 6.3 (Swiss Academic Software GmbH, Wädenswil, Switzerland). In the first selection step, a screening of titles was carried out. In the next step, abstracts were screened for eligibility. Abstracts meeting the criteria were further examined by reading the full text articles. Full texts were also read for studies that had abstracts providing insufficient information about eligibility. Potential studies for inclusion in the review were scanned by at least two reviewers. Disagreements regarding inclusion were solved by discussion. Also, a third independent opinion of a reviewer was considered. Consensus was then achieved in 100% of the cases.

Data Extraction

The descriptive data of each included study were included in an item extraction form by two reviewers and differences solved by discussion. The item extraction contained source (authors, year of publication), sample (sample size, period of testing, country, age), measurements, and PF test items allocated to the different dimensions of PF, relevant for secular trends.

Data Treatment

To determine secular trends in PF of children and adolescents, only relevant results of the studies included were extracted, including changes and differences for the specific test performances between at least two or more measurement points. Findings from studies were further divided into subsamples based on PF test items and by sex. For example, a study which reported two different test items for strength, i.e., sit-ups and standing broad jump, and one test item for endurance, i.e., shuttle-run, each for boys and girls, led to six different subsamples which we analysed as part of this review. We chose this procedure as it appeared useful to report results in a more specific and detailed way, especially with regard to different PF trends within a given sample. After building subsamples, we analysed the reported findings and categorized them into three possible trends, i.e., increase, stagnation, and decline. Nonsignificant changes were considered as stagnation. There were no general cut-offs or categories for decrease or increase. We did not analyze the raw data in the present review, but assessed the available results as a decrease or increase if the authors judged the results to be statistically relevant, based on their findings for the respective study.

Quality Assessment

Quality of the studies included was assessed independently by two reviewers using the Effective Public Health Practice Project (EPHPP) assessment tool. The EPHPP assessment tool is a standardized method used for quantitative studies in public health research. This tool incorporates selection bias across participants, study design, confounders, blinding of researchers and participants, data collection methods, withdrawals, and drop-outs in a global quality rating that differentiates between weak, moderate, and strong. Quality was considered strong when none of the items was graded as weak, moderate quality was considered with one weak rating, and weak quality was the result of two or more weak ratings (Thomas et al., 2004).

Results

A total of 3421 studies were identified during the initial PubMed search. After the screening titles stage, 587 studies remained. Abstract screening yielded 94 full text articles assessed for eligibility. Twenty-four studies were included in the review for final analysis. Please refer to Figure 1 for a flow chart of the study selection process.

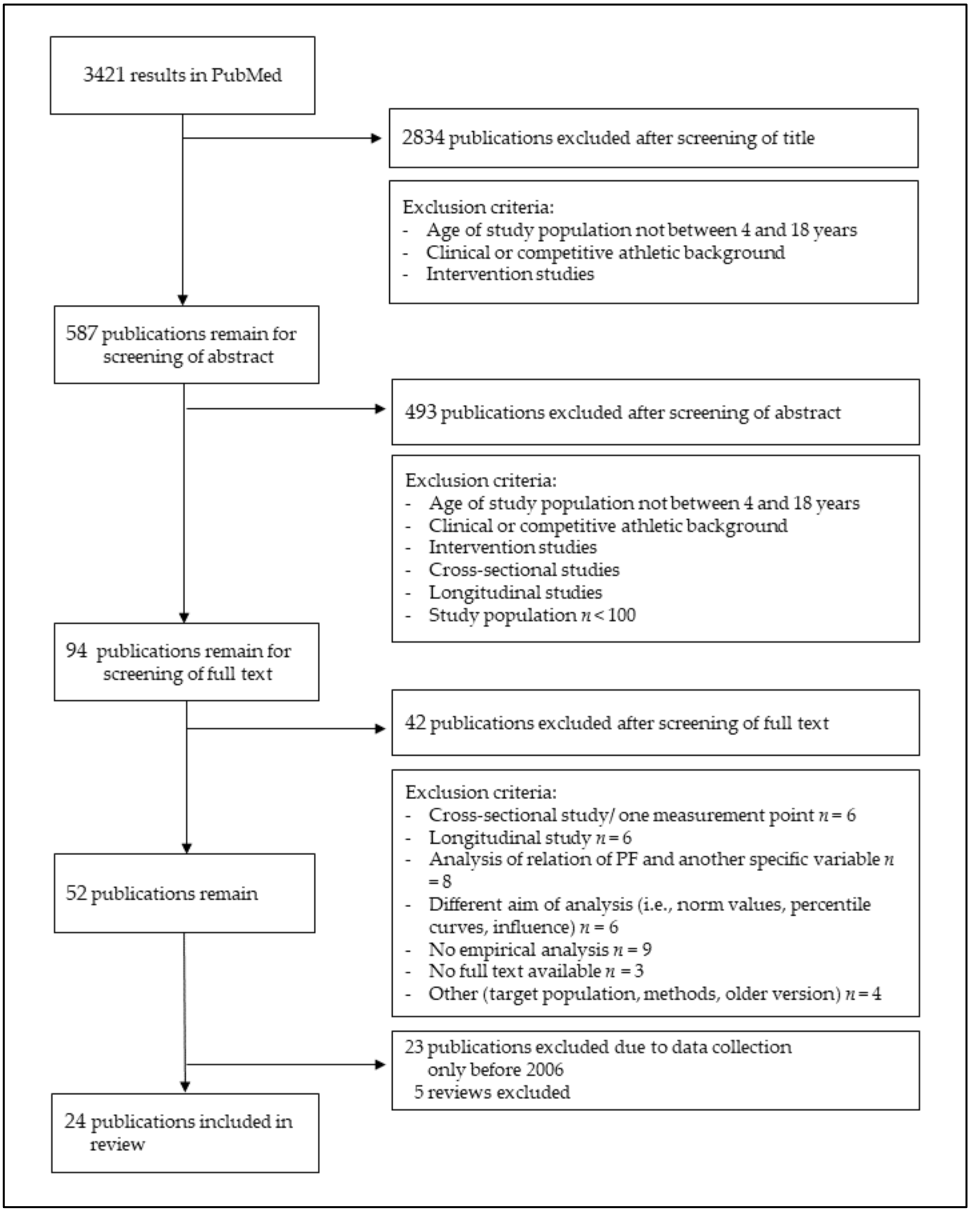

Figure 1 Flow chart of study selection process

Study Characteristics

Sixteen studies were conducted in Europe (Boddy et al., 2012; Cohen et al., 2011; Costa et al., 2017; Dyrstad et al., 2012; Ekblom et al., 2011; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Palomäki et al., 2015; Roth et al., 2010; Sandercock et al., 2015; Sandercock & Cohen, 2019; Sedlak et al., 2015; Smpokos et al., 2012; Spengler et al., 2017; Tambalis et al., 2011; Venckunas et al., 2017), three studies in North America (Bai et al., 2017; Morales-Demori et al., 2017; Tremblay et al., 2010), two studies in Australia (Fraser et al., 2019; Hardy et al., 2018), one in China (Ao et al., 2019), one in Mozambique (Dos Santos et al., 2015), and one in Brazil (Moraes Ferrari et al., 2013). The 24 studies included were published between 2010 (Moliner-Urdiales et al., 2010; Roth et al., 2010; Tremblay et al., 2010) and 2019 (Ao et al., 2019; Fraser et al., 2019; Sandercock & Cohen, 2019), and seven of them had at least two measurement points (Cohen et al., 2011; Fraser et al., 2019; Hardy et al., 2018; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Palomäki et al., 2015; Tremblay et al., 2010). The earliest data used in the studies were collected in 1969 (Dyrstad et al., 2012) and the latest in 2015 (Fraser et al., 2019; Hardy et al., 2018; Spengler et al., 2017). Sample sizes ranged from 435 (Morales-Demori et al., 2017) to 651,582 (Tambalis et al., 2011), and a total of over 860,000 children and adolescents were examined in the studies. The participants were eleven-years old on average, with ages ranging between 3 to 18 years. Sex was equally distributed. In all studies, male and female subjects participated. Study characteristics are summarized in detail in Table 1.

Table 1 Characteristics of included studies

Reference	***Country***	***Period***	***Measurements***	***Age***	***Sample size***	***Dimension of MP***	***Test Items***
Ao et al. [1]	*China*	*1985-2014*	*1 per year, 7 overall*	*12*	*136,566*	*Endurance, strength, speed*	*10*50SR; SBJ, SU, 50m,*
Bai et al. [2]	*USA*	*2012-2014*	*1 per year, 3 overall*	*5-18*	*6,318*	*Endurance*	*20SR*
Boddy et al. [3]	*UK*	*1998-2010*	*1 per year, 12 overall*	*9-10.9*	*14,247*	*Endurance*	*20SR*
Cohen et al. [4]	*UK*	*1998-2008*	*1 per year, 2 overall*	*10-10.9*	*624*	*Strength*	*SBJ, SU, HG, BAH*
Costa et al. [5]	*Portugal*	*1993-2013*	*1 per year, 4 overall*	*10-11*	*1,819*	*Strength, speed, flexibility*	*SBJ; SU; 40m; SAR*

Dos Santos et al. [6]	*Mozambique*	*1992-2012*	*1 per year, 3 overall*	*8-15*	*3,851*	*Endurance, strength, speed, flexibility*	*1mile, HG, 10*5SR, SAR*
Dyrstad et al. [7]	*Norway*	*1969-2009*	*1 per year, over 40 overall*	*16-18*	*4,006*	*Endurance*	*3000m*
Ekblom et al. [8]	*Sweden*	*1987-2007*	*1 per year, 3 overall*	*16*	*1,023*	*Endurance*	*SME*
Fraser et al. [9]	*Australia*	*1985-2015*	*1 per year, 2 overall*	*11-12*	*3,732*	*Strength*	*SBJ*
Hardy et al. [10]	*Australia*	*1985-2015*	*1 per year, 2 overall*	*9-15*	*7,081*	*Strength*	*SBJ*
Moliner-Urdiales et al. [11]	*Spain*	*2001-2007*	*1 per year, 2 overall*	*12.5 - 17.5*	*791*	*Endurance, strength, speed*	*20SR; SBJ, HG, BAH, 4*10SR*
Moraes Ferrari et al. [12]	*Brazil*	*1978-2010*	*1 per year, 4 overall*	*10-11*	*1,291*	*Endurance*	*SME*
Morales-Demori et al. [13]	*USA*	*1983-2010*	*1 per participant*	*4-18*	*435*	*Endurance*	*BTP*
Müllerova et al. [14]	*Czech Republic*	*1987-2013*	*1 per year, 2 overall*	*8-13*	*896*	*Strength, speed*	*SBJ, SU, 4*10SR*
Palomäki et al. [15]	*Finland*	*2003-2010*	*1 per year, 2 overall*	*15-16*	*3,559*	*Endurance*	*20SR*
Roth et al. [16]	*Germany*	*1973-2007*	*1 per year, 4 overall*	*3- 6*	*2,293*	*Strength, coordination*	*SBJ, Obstacle Course, BB, TT*
Sandercock et al. [17]	*UK*	*1998-2014*	*1 per year, 3 overall*	*10-11*	*925*	*Endurance*	*20SR*
Sandercock et al. [18]	*UK*	*1998-2014*	*1 per year; 3 overall*	*10*	*920*	*Strength*	*SBJ, HG, SU, BAH*
Sedlak et al. [19]	*Czech Republic*	*1977-2012*	*1 per year, 6 overall*	*5- 6*	*3,768*	*Strength*	*SBJ, BT*
Smpokos et al. [20]	*Greece*	*1992-2007*	*1 per year, 2 overall*	*6- 7*	*967*	*Endurance, strength, flexibility*	*20SR, SBJ, SU, SAR*
Spengler et al. [21]	*Germany*	*2006-2015*	*1 per year, 10 overall*	*6- 7*	*5,001*	*Endurance, speed, coordina-*	*6min, 20m, SLS*

						tion	
Tambalis et al. [22]	*Greece*	*1981-2007*	*1 per year, 10 overall*	*8- 9*	*651,582*	*Endurance, strength, speed*	*20SR, VJ, BT, 30m*
Tremblay et al. [23]	*Canada*	*1981-2009*	*1 per year, 2 overall*	*7-19*	*7,203*	*Strength, flexibility*	*HG, SAR*
Venckunas, et al. [24]	*Lithuania*	*1992-2012*	*1 per year, 3 overall*	*11-18*	*16,199*	*Endurance, strength, speed, flexibility, coordination*	*20SR, SBJ, SU, BAH, 10*5SR, SAR, SLS*

Abbreviations: BAH= Bent-arm hang; BB= Balancing backwards; BT= Ball hrow; BTP= Bruce treadmill protocol; HG= Hand grip; SAR= Sit-and-Reach; SBJ= Standing broad jump; SLS= Single leg stand; SME= Submaximal ergometer test; SU= Sit ups; TT= Target throwing; 4*10SR= 4*10m shuttle run; 10*5SR= 10*5m shuttle run; 10*50SR= 10*50m shuttle run; 20SR= 20m shuttle run;; 1mile= 1 mile run; 3000m= 3000 m run; 20m= 20 m run; 30m= 30 m run; 40m= 40 m run; 50m= 50m run; 6min= 6 min run

Study Quality

Two studies were classified as strong (Dyrstad et al., 2012; Palomäki et al., 2015), 21 studies as moderate (Ao et al., 2019; Bai et al., 2017; Boddy et al., 2012; Cohen et al., 2011; Costa et al., 2017; Dos Santos et al., 2015; Ekblom et al., 2011; Fraser et al., 2019; Hardy et al., 2018; Moliner-Urdiales et al., 2010; Moraes Ferrari et al., 2013; Morales-Demori et al., 2017; Palomäki et al., 2015; Roth et al., 2010; Sandercock et al., 2015; Sandercock & Cohen, 2019; Sedlak et al., 2015; Smpokos et al., 2012; Spengler et al., 2017; Tambalis et al., 2011; Tremblay et al., 2010; Venckunas et al., 2017), and one study as weak (Müllerová et al., 2015). Due to lacking documentation of withdrawals and drop-outs, most of the studies received a weak rating for this item. This leads to a lower overall rating of these studies. In all studies, data collection methods were considered to be valid and reliable. Regarding an assessment by different dimensions of PF, validity of physical condition tests seems to be higher than that of motor coordination tests (see section Discussion). For this reason, all studies reached a strong rating for this item, reflecting a high-quality main outcome measurement of PF. For PF measurement three relevant confounders were identified, which should be considered in the statistical analysis and were also considered in a separate quality item. If BMI, age, and gender were controlled, we state 80–100% agreement and if only age and gender were controlled, 60–79% agreement was reached for the question of control for relevant confounder. In every study at least some of the relevant confounders were considered. See Table S1 (EPHPP Assessment for included studies) for detailed information on the rating of each study.

Trends in Physical Fitness

To assess secular trends in the PF of children and adolescents, 15 of the 24 studies included carried out test items for endurance (Ao et al., 2019; Bai et al., 2017; Boddy et al., 2012; Dos Santos et al., 2015; Dyrstad et al., 2012; Ekblom et al., 2011; Moliner-Urdiales et al., 2010; Moraes Ferrari et al., 2013; Morales-Demori et al., 2017; Palomäki et al., 2015; Sandercock et al., 2015; Smpokos et al., 2012; Spengler et al., 2017; Tambalis et al., 2011; Venckunas et al., 2017). Fifteen studies used test items for strength (Ao et al., 2019; Bai et al., 2017; Costa et al., 2017; Dos Santos et al., 2015; Dyrstad et al., 2012; Hardy et al., 2018; Moraes Ferrari et al., 2013; Palomäki et al., 2015; Roth et al., 2010; Sandercock et al., 2015; Sedlak et al., 2015; Smpokos et al., 2012; Tambalis et al., 2011; Tomkinson et al., 2018; Venckunas et al., 2017), eight for speed (Ao et al., 2019; Costa et al., 2017; Dos Santos et al., 2015; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Spengler et al., 2017; Tambalis et al., 2011; Venckunas et al., 2017), five for flexibility (Costa et al., 2017; Dos Santos et al., 2015; Smpokos et al., 2012; Tremblay et al., 2010; Venckunas et al., 2017), and three for coordination (Roth et al., 2010; Spengler et al., 2017; Venckunas et al., 2017). A total of 22 different specific test items for PF were carried out in the included studies, but not all were used for analysis. Studies assessing endurance mostly utilized the 20 m shuttle run test (Bai et al., 2017; Boddy et al., 2012; Moliner-Urdiales et al., 2010; Palomäki et al., 2015; Sandercock et al., 2015; Smpokos et al., 2012; Tambalis et al., 2011; Venckunas et al., 2017) and the 10×50 m shuttle run test (Ao et al., 2019). They also used time-related (6 min run (Spengler et al., 2017)), as well as distance-related endurance tests (1-mile run (Dos Santos et al., 2015), 3000 m run (Dyrstad et al., 2012)). Three studies included submaximal ergometer testing (Ekblom et al., 2011; Moraes Ferrari et al., 2013) or a treadmill test following the Bruce protocol (Morales-Demori et al., 2017). Studies assessing strength covered specific test items for different body extremities and the trunk. For the upper limbs and the trunk, handgrip (Cohen et al., 2011; Dos Santos et al., 2015; Moliner-Urdiales et al., 2010; Sandercock et al., 2015; Tremblay et al., 2010; Venckunas et al., 2017), bent-arm hang (Cohen et al., 2011; Moliner-Urdiales et al., 2010; Sandercock & Cohen, 2019; Venckunas et al., 2017), ball throw (Sedlak et al., 2015; Tambalis et al., 2011), and sit-up tests (Ao et al., 2019; Cohen et al., 2011; Costa et al., 2017; Müllerová et al., 2015; Sandercock & Cohen, 2019; Smpokos et al., 2012; Venckunas et al., 2017) were accomplished. To assess strength of the lower limbs, the standing broad jump test (Ao et al., 2019; Cohen et al., 2011; Costa et al., 2017; Fraser et al., 2019; Hardy et al., 2018; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Roth et al., 2010; Sandercock & Cohen, 2019; Sedlak et al., 2015; Venckunas et al., 2017) or a vertical jump test (Tambalis et al., 2011) was carried out. For assessing speed, sprints over a short distance (20 m (Spengler et al., 2017), 30 m (Tambalis et al., 2011), 40 m (Costa et al., 2017), 50 m (Ao et al., 2019)) or short shuttle run tests, such as the 4×10 m shuttle run (Moliner-Urdiales et al., 2010; Müllerová et al., 2015) or the 5×10 m shuttle run (Dos Santos et al., 2015; Venckunas et al., 2017), were made. All studies assessing flexibility used the sit-and-reach test (Costa et al., 2017; Dos Santos et al., 2015; Smpokos et al., 2012;

Tremblay et al., 2010; Venckunas et al., 2017). Assessment of coordinative abilities included an obstacle course, target throwing, or balancing backwards (Roth et al., 2010; Spengler et al., 2017; Venckunas et al., 2017). For an overview of all test items used in the studies to assess the different dimensions of PF, see Table 1.

Within the 24 studies included, there were 148 subsamples: 35 subsamples reported an increase of PF, 20 subsamples showed stagnation with no significant changes over the period analysed, and 93 subsamples found a negative trend in different PF tests. Results of trends in PF for the specific dimensions are presented in Table 2.

Table 2. Results of trends in PF for the specific dimensions of PF. A significant result is rated as increase or decrease; a nonsignificant result is rated as stagnation)

Motor Tests for Endurance	***Trends in Subsamples (Number of Categorized Subsamples)***		
	Increase	***Stagnation***	***Decline***
10×50 m run			*[1] (4)*
20 m- shuttle run	*[2] (3); [11] (2); [20] (2)*	*[2] (3); [15] (2)*	*[3] (2); [17] (2); [22] (2); [24] (2)*
1 mile run			*[6] (2)*
3000 m run			*[7] (2)*
Submaximal ergometer test			*[8] (2); [12] (2)*
Bruce treadmill test			*[13] (2)*
6 min run		*[21] (1)*	*[21] (1)*
∑ endurance: 15 studies (36 subsamples)	*∑ (7)*	*∑ (6)*	*∑ (23)*
Motor tests for strength	***Trends in subsamples (number of categorized subsamples)***		
	Increase	***Stagnation***	***Decline***
Standing broad jump	*[4] (2); [16] (2); [20] (2)*	*[5] (2); [16] (2) [22] (2)*	*[1] (4); [9] (2); [10] (4); [11] (2); [14] (4); [18] (2); [19] (2); [24] (2)*
∑ leg strength: 13 studies (34 subsamples)	*∑ (6)*	*∑ (6)*	*∑ (22)*
Bent-arm hang		*[11] (2)*	*[4] (2); [18] (2); [24] (2)*
∑ arm strength: 4 studies (8 subsamples)	*∑ (0)*	*∑ (2)*	*∑ (6)*
Handgrip test	*[6] (1)*		*[4] (2); [6] (1); [11] (2); [18] (2); [23] (2)*
∑ grip strength: 5 studies (10 subsamples)	*∑ (1)*	*∑ (0)*	*∑ (9)*

Sit-ups	*[1] (2); [5] (2); [20] (2); [24] (1)*	*[24] (1)*	*[1] (2); [4] (2); [14] (4); [18] (2)*
∑ trunk strength: 7 studies (18 subsamples)	*∑ (7)*	*∑ (1)*	*∑ (10)*
Motor tests for speed	***Trends in subsamples (number of categorized subsamples)***		
	Increase	***Stagnation***	***Decline***
4×10 m shuttle run	*[11] (2)*		*[14] (4)*
10×5 m shuttle run		*[24] (2)*	*[6] (2)*
50 m sprint	*[1] (1)*		*[1] (3)*
40 m sprint	*[5] (1)*		
30 m sprint	*[22] (2)*	*[5] (1)*	
20 m sprint	*[21] (2)*		
∑ speed: 8 studies (20 subsamples)	*∑ (8)*	*∑ (3)*	*∑ (9)*
Motor tests for flexibility	***Trends in subsamples (number of categorized subsamples)***		
	Increase	***Stagnation***	***Decline***
Sit-and-reach	*[20] (2)*		*[5] (2); [6] (2); [23] (4); [24] (2)*
∑ flexibility: 5 studies (12 subsamples)	*∑ (2)*	*∑ (0)*	*∑ (10)*
Motor tests for coordination	***Trends in subsamples (number of categorized subsamples)***		
	Increase	***Stagnation***	***Decline***
Obstacle course		*[16] (2)*	
Balancing backwards			*[16] (2)*
Target throwing			*[33] (2)*
One leg stand	*[38] (2); [40] (2)*		
∑ coordination: 3 studies (10 subsamples)	*∑ (4)*	*∑ (2)*	*∑ (4)*

∑= sum of subsamples

Endurance

Fifteen studies include test items for endurance, which resulted in 36 subsamples. Seven subsamples showed an increase in endurance performance, which was assessed with the 20 m shuttle run test (Bai et al., 2017; Moliner-Urdiales et al., 2010; Morales-Demori et al., 2017; Smpokos et al., 2012). For example, comparison of studies conducted in Spain in 2001 and 2007 show that participants reached higher stages in the shuttle run test, indicating better endurance at the later time point. In 2001, boys aged between 12.5 and 17.5 reached 6.7 stages ± 2.4 and in 2007 7.7 stages ± 2.4 (Cohens d = 0.41; p = 0.001) [30]. The performance in the 20 m shuttle run test of 6- to 7-year-old children in Greece between 1992 and 2007 differed by 21% for boys and 26% for girls (Smpokos et al., 2012).

Stagnation of endurance performance was observed in six subsamples (Bai et al., 2017; Palomäki et al., 2015; Spengler et al., 2017). For example, Palomäki et al. (2015) found no significant changes in the sample of Finnish adolescents between 2003 and 2010.

The majority of studies (i.e., 23 subsamples) suggested a decline in endurance performance in children and adolescents (Ao et al., 2019; Boddy et al., 2012; Dos Santos et al., 2015; Dyrstad et al., 2012; Ekblom et al., 2011; Moraes Ferrari et al., 2013; Morales-Demori et al., 2017; Sandercock et al., 2015; Spengler et al., 2017; Tambalis et al., 2011; Venckunas et al., 2017). In a Norwegian cohort study, 3000 m running time increased by 10% for boys and 6% for girls over three decades (Dyrstad et al., 2012). There was, however, a large variability in the amount of decline in the 20 m shuttle run test. Sandercock et al. (2015) found an annual decline of 0.7% for boys and 0.9% for girls between 1998 and 2008 in 10 to 11-year-old children from England and the updated data of 2014 confirmed this upward trend. Lithuanian schoolchildren achieved almost twice as high stages in the 20 m shuttle run test in 1992 compared to the latest measurement in 2012. However, the decline became smaller between 2002 and 2012 (Venckunas et al., 2017). A stratification of performance in quartiles according to BMI-categories showed that the percentages of both genders in the quartile of excellent performance decreased substantially, while the poor percentage in the poor performance quartile increased within all BMI-categories. For example, the percentage of normal-weight boys in the excellent quartile was 36.3% in 1997 and decreased to 21.1% in 2007. In turn, the percentage changes for the poor quartile rose from 21.8% in 1997 to 32.1% in 2007 (Tambalis et al., 2011).

The mean annual decline reported by Boddy et al. (2012), who conducted twelve different measurements between 1998 and 2010, was 1.34% for boys and 2.29% for girls.

Strength

For lower limb and leg strength, 13 studies with 34 subsamples were identified and most of them utilized standing broad jump (Ao et al., 2019; Cohen et al., 2011; Costa et al., 2017; Fraser et al., 2019; Hardy et al., 2018; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Roth et al., 2010; Sandercock & Cohen, 2019; Sedlak et al., 2015; Smpokos et al., 2012; Venckunas et al., 2017). Six subsamples found a trend towards increased performance (Cohen et al., 2011; Roth et al., 2010; Smpokos et al., 2012). Greek boys aged 6 to 7 years jumped 0.36 m farther in the 2006/2007 cohort compared to 1992/1993 (Smpokos et al., 2012). The difference in 10 to 11-year-old children from the UK was approximately 0.07 m between 1998 and 2008 (Cohen et al., 2011), and German children also significantly increased their standing broad jump performance between 1989 and 2007 (Roth et al., 2010). Two studies with four subsamples found no significant changes during a time period of ten years (Costa et al., 2017; Tambalis et al., 2011). Also, Roth et al. (2010) reported no change in performance. Twenty-two subsamples, therefore most of the studies, suggested a decreasing trend for the lower limb strength in children and adolescents (Ao et al., 2019; Fraser et al., 2019; Hardy et al., 2018;

Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Roth et al., 2010; Sandercock & Cohen, 2019; Sedlak et al., 2015; Venckunas et al., 2017). For Australian children aged 11 to 12 years, the mean difference between 1985 and 2015 was 0.11 m (Fraser et al., 2019), and 9 to 15-year-old children jumped approximately 0.07 m shorter in the later measurement point (Hardy et al., 2018). Moliner-Urdiales et al. (2010) reported a decrease of 0.09 m for boys and 0.12 m for girls from 2001 to 2007 in Spain. Other European studies also found a negative trend (Müllerová et al., 2015, 2015; Sandercock & Cohen, 2019; Venckunas et al., 2017). In contrast to this, China first reported an increase in standing broad jump performance until 1995, which was followed by a decline until the last measurement in 2014 (Ao et al., 2019).

For upper limb strength and more specifically, arm strength, the bent-arm hang test was performed in four studies with eight subsamples (Cohen et al., 2011; Moliner-Urdiales et al., 2010; Sandercock & Cohen, 2019; Venckunas et al., 2017). None of the studies reported an increasing trend of performance. Between 2001 and 2007, hang time was similar and no changes were found in Spanish adolescents (Moliner-Urdiales et al., 2010). Apart from this stagnation, three studies with six subgroups reported a decline in upper body strength (Cohen et al., 2011; Sandercock & Cohen, 2019; Venckunas et al., 2017). In the study of Cohen et al. (2011) on 10-year-old children, significant annual declines by 1.27% for boys and 2.27% for girls were shown. In the extension of Sandercock et al. (2019) with a third measurement conducted in 2014, this trend continued. Over the 20 years that were analysed, the decline in hanging time of Lithuanian children was most pronounced during the last decade, from 2002 to 2012 (Venckunas et al., 2017).

In five studies with ten subsamples, the handgrip test was assessed (Cohen et al., 2011; Dos Santos et al., 2015; Moliner-Urdiales et al., 2010; Sandercock & Cohen, 2019; Tremblay et al., 2010). Dos Santos et al. (2015) reported an increase for boys from 20.11 kg to 20.95 kg and 22.51 kg over the years 1992, 1999, and 2012. For girls, however, a decline was observed. The negative trend was also found in nine of the ten subsamples. Canadian children showed a significant negative change over all examined age groups from 6 to 19 years between 1981 and 2009. Handgrip strength in boys aged 11 to 14 years was 6 kg lower in the second cohort and in 15 to 19-year-old girls handgrip strength decreased from 60 kg to 54 kg (Tremblay et al., 2010). The shorter time period from 2001 to 2007 revealed a significant decrease of 4.5 kg for Spanish adolescents (Moliner-Urdiales et al., 2010). The most recent measurement in 2014 for 10-year-old English girls also revealed lower handgrip in 2014 compared to 2008 and 1998 (Sandercock & Cohen, 2019).

Sit-ups were utilized to measure trunk strength in seven different studies and 18 subsamples (Ao et al., 2019; Cohen et al., 2011; Costa et al., 2017; Müllerová et al., 2015; Sandercock & Cohen, 2019; Smpokos et al., 2012; Venckunas et al., 2017). Greek and Portuguese children improved their performance from 1993 to 2013 (Costa et al., 2017) and 1992 to 2007, respectively (Smpokos et al., 2012). The 6 to 7-year-old boys performed 4.8 and girls 5.2 more repetitions at the second measurement (Smpokos et al., 2012). One of the subsamples, however, displayed a stagnation of trunk strength (Venckunas et al., 2017), while four studies with ten subsamples showed a decline (Ao et al., 2019; Cohen et al., 2011; Müllerová et al., 2015; Sandercock & Cohen, 2019). For example, sit-up performance in English children declined by 27% from 1998 to 2008 and by an additional 19% from 2008 to 2014 (Cohen et al., 2011; Sandercock & Cohen, 2019). Earlier measurements in a Chinese sample showed an initial increase from 1985 until 2000, which was subsequently followed by a decline in the following five years (Ao et al., 2019).

Speed

Eight of the studies included 20 subsamples focused on speed performance of children and adolescents (Ao et al., 2019; Costa et al., 2017; Dos Santos et al., 2015; Moliner-Urdiales et al., 2010; Müllerová et al., 2015; Spengler et al., 2017; Tambalis et al., 2011; Venckunas et al., 2017). Five studies reported an increase of speed over time in eight subsamples (Ao et al., 2019; Costa et al., 2017; Müllerová et al., 2015; Spengler et al., 2017; Tambalis et al., 2011). When the 30 m sprint of Greek 8 to 9-year-old children was stratified into quartiles, the percentage of normal-weight girls in the excellent quartile increased from 28.6% in 1997 to 34.9% in 2007 (Tambalis et al., 2011). Likewise, Spanish adolescents aged 12.5 to 17.5 years improved their speed between 2001 and 2007 (Moliner-Urdiales et al., 2010), and German 6-year old children showed a mean improvement of 2.7% (boys) and 4.3% (girls) per decade (Spengler et al., 2017).

Three subsamples, by contrast, reported a stagnation of speed (Costa et al., 2017; Venckunas et al., 2017). Even though Venckunas et al. (2017) found an improvement for boys between 1992 and 2002, no change was shown from 2002 to 2012 and there was no change in girls for the entire study period. In addition, Portuguese girls did not exhibit any significant change over 30 years (Costa et al., 2017).

Three studies with nine subsamples reported a decline in sprint performance (Ao et al., 2019; Dos Santos et al., 2015; Müllerová et al., 2015; Spengler et al., 2017). Chinese girls at an age of 12 became slower over the measurements from 1985 until 2014 (Ao et al., 2019). In 1992, Mozambican 8- to 15-year-old boys needed 21.88 s to finish the 5×10 m shuttle run test; in 2012, they needed 22.51 s. The same trend was observed for girls, who needed 22.49 s in 1992 and 23.66 s in 2012 (Dos Santos et al., 2015).

Flexibility

All five studies with 12 subsamples measured flexibility with the sit-and-reach test (Costa et al., 2017; Dos Santos et al., 2015; Smpokos et al., 2012; Tremblay et al., 2010;

Venckunas et al., 2017). One study from Greece reported a positive secular trend, i.e., Smpokos et al. (2012) observed an increase of 22% for boys and 13% for girls between 1992 and 2007.

In contrast to this, the other four studies reported a decrease in flexibility over time (Costa et al., 2017; Dos Santos et al., 2015; Tremblay et al., 2010; Venckunas et al., 2017). Mozambican 8- to 15-year old children were less flexible in 2012 and 2002 than in 1992. For example, performance of girls decreased from 38.03 cm in 1992 to 36.52 cm in 2002 to 35.41 cm in 2012 (Dos Santos et al., 2015). A similar trend of decreasing flexibility was observed for Lithuanian children (Venckunas et al., 2017). In line with this, Tremblay et al. (2010) analysed trends of performance in the sit-and-reach test of Canadian children and adolescents, and reported lower flexibility in 2009 compared to 1981 across all age groups; i.e., performances of the 15 to 19-year-old boys decreased significantly from 30 cm to 24 cm.

Coordination

Three studies were found to assess coordination, which resulted in 10 subsamples using various tests (Roth et al., 2010; Spengler et al., 2017; Venckunas et al., 2017). Spengler et al. (2017) found a relatively strong positive trend in the static stand test for German 6-year-old children with values increasing by 22.8% (boys) and 41.1% (girls) between 2006 and 2015. Similarly, balance performance of Lithuanian children and adolescents aged 11 to 18 years improved from 1992 to 2012 (Venckunas et al., 2017). This effect was observed for all age groups but was more pronounced for girls than for boys. Roth et al. (2010) reported no change in coordination performance between 1989 and 2007. However, the authors reported a decline for 3 to 6-year-old children in balancing backwards and target-throwing tasks between 1985 and 2007 (Roth et al., 2010).

Discussion

The aim of this review was to conduct a literature review of secular trends in PF of children and adolescents in large-scale epidemiological studies, which have at least one measurement in or after 2006.

Within the 24 studies included, there were 148 subsamples: 35 subsamples (24%) reported an increase of PF, 20 (13%) a stagnation with no significant changes over the analysed period, and 93 subsamples (63%) found a negative trend in different PF test items.

For endurance, 23 subsamples showed a declining trend, seven subsamples an increase, and six subsamples a stagnation. The declining trend is especially obvious in studies with measurement times that are older and with long time periods between follow-ups (Ao et al., 2019; Moraes Ferrari et al., 2013; Morales-Demori et al., 2017). The same findings were supported with the latest study by Greier et al. (2019), who analysed Tyrolean boys aged 10 to 14 years. Over the measurement time points in 1972 and 2015, endurance declined by 15% (Greier et al., 2019). In addition, for Chinese children and adolescents, Bi et al. (2020) showed a decline between the latest measurement points of 1995 and 2014, and a stagnation from 1985 until 1995. Increase and stagnation of endurance were mostly found in studies covering measurements after 2000 (Moliner-Urdiales et al., 2010; Palomäki et al., 2015; Venckunas et al., 2017). These findings are partly in line with a recent review of Tomkinson et al. (2019) that covered 137 studies with measurement periods from 1981 until 2014. Cardiorespiratory fitness decreased in the 1980s and 1990s, especially, but with a slowing trend since the 2000s. The decline then stabilized (Tomkinson et al., 2019).

For strength, 47 of the 70 subsamples showed a decline. Most of the studies reporting a decline were characterized by long time periods between follow-ups. The findings were highly inconsistent, depending on the part of body for which the strength test was conducted.

This inconsistency within findings for certain parts of the body was also obvious in several other studies. Albon et al. (2010) found an increase for performance of sit-ups, but no significant changes for standing broad jump between 1991 and 2003. Tomkinson et al. (2007), by contrast, analysed data of over 20 million young people from 27 countries with measurements between 1958 and 2003 and found a general increase by 0.03% per year for the lower limbs. From the late 1950s until the 1980s, performance in standing broad jump increased consistently and then stabilized before a 15-year decline. Huotari et al. (2010) reported no significant changes in standing broad jump for Finnish adolescents, a decline for the bent arm hang, but an increase for sit-ups.

For speed, the 20 subsamples can be divided into eight subsamples showing an increase, three revealing stagnation, and nine exhibiting a decline. For this reason, it is impossible to determine a direction of trend. Other research yielded the same results. Matton et al. (2007) reported an increase of performance of Flemish adolescents between 1969 and 2005, while the performance of Estonian and Lithuanian children and adolescents measured in 1992 and 2002 did not change (Jürimäe et al., 2007). An overall increase of 0.04% per year was found by Tomkinson et al. (2007) when analysing data measured between 1958 and 2003. Since 1985, however, this increase has stabilized at values close to zero.

For flexibility, a declining trend was found in the studies. In ten of 12 subsamples, the children's performance in sit-and-reach tests declined.

For coordination, only ten subsamples of the studies included could be analysed and this less evidence was specified even more through targeting different aspects of coordination tasks. Roth et al. (2010) found stagnation and decline for different coordination tests, whereas the two other studies revealed an increase (Spengler et al., 2017; Venckunas et al., 2017).

There is still some uncertainty in these findings as the comparisons are based on independent samples and sampling effects cannot be excluded. However, most of the results confirm the results of previous reviews (Bös, 2003; Bös et al., 2008; Tomkinson et al., 2019) and are therefore consistent. It is crucial that PF components are analysed separately because all components showed different patterns of secular trends over time and demonstrate the essential need for a detailed assessment of trends. The negative trends especially in endurance are alarming, although they slowed down in recent years. Cardiorespiratory fitness represents a key to health in later life. In particular, it is important to keep the absolute level of performance in mind when considering trends, whether positive or negative. Even slight positive changes may only reduce the negative relative change in recent years and, thus, only lead to "stagnation of PF on a low level."

Given the proven correlation between PF and physical and mental health (Bös et al., 2017), a "stagnation of PF on a low level" of children and adolescents cannot be the target state. To ensure an active and healthy lifestyle, it is crucial to adequately promote PF of children and adolescents. Regular and consistent monitoring with a standardized method should be implemented internationally and supported by important decision-makers. A common monitoring is recommended to design interventions and programs on a reliable database and should be a strategic aim of international sports policy institutions.

To solve the problem of low comparability of the primary studies analysed for this narrative review (e.g., different methods, definitions, and samples), eResearch infrastructure should be implemented for storing, linking, and reusing the data. Sustainable access to data enables collaborative work and makes research comprehensible and reusable across disciplinary boundaries. For PF test data, the sport scientific eResearch infrastructure MO|RE data was developed, to store, combine, and evaluate data. The research results are made publicly accessible and citable via the platform (Kloe, 2021).

The results are even more difficult to compare due to different sample sizes, statistical analyses, measurement points, and methods. In this context, various other aspects, i.e., socioeconomic status, educational system, and geographical regions, should be considered (Hanssen-Doose et al., 2021; Tomkinson, 2007).

Coordination is considered an important part of the concept of health-oriented fitness (Bouchard et al., 2012). However, the exact recording of coordinative aspects and their correct interpretation, as well as the comparability of different coordination results are difficult.

Firstly, the construct of coordinative abilities is complex and multidimensional; i.e., different coordination tasks can measure different aspects of coordination (e.g., reaction ability, orientation ability).

Secondly, coordination tasks are usually assessed qualitatively, which makes it difficult to determine trends in coordination. Qualitatively assessed test items often are associated with a low reliability. Estimating reliability for characteristics with a reduced level of characteristic expression (e.g., dichotomous characteristics or ordinal characteristics) is problematic, since correlation coefficients are dependent on both variance and difficulty (Bös & Mechling, 1983). It is therefore more difficult to maintain quality criteria for coordination than for interval-scale test items (e.g., strength, endurance) (Tittlbach et al., 2005). In summary, for the assessment of trends this means that the results for coordination are not comparable with the results of the more reliable interval-scaled physical condition test items, due to the methodological difficulties mentioned above.

A long time between the first and the last measurements seems to lead to more changes over time in PF. Time should not be too long to obtain a reasonable development. It is recommended to measure PF not only in the beginning and at the end of an investigation, but at periodic intervals for regular and continuous monitoring (Hanssen-Doose et al., 2021). In Germany, these requirements are met by the MoMo Study, a nationwide large cohort study that examines trends in PF, already with three waves of measurements since 2003 (Hanssen-Doose et al., 2021).

When assessing the subsamples, some differences are also due to age and gender. The study by Smpokos et al. (2012), which found an increase of endurance, strength, and flexibility, disagreed with the overall findings. The study population was 6 to 7-year-olds. Differences due to age were also found in Australian children with a decreasing trend for older children. Increase was found mainly for children below the age of nine (Cohen et al., 2011; Roth et al., 2010; Smpokos et al., 2012; Spengler et al., 2017; Tambalis et al., 2011), while subsamples with older children tend to show even smaller values (Dyrstad et al., 2012; Ekblom et al., 2011; Palomäki et al., 2015).

All of the studies included analysed gender-specific differences. Spengler et al. (2017) found a decreasing trend in boys´ endurance, but no significant changes for girls. Lithuanian girls increased their performance in sit-ups, while boys did not (Venckunas et al., 2017). Costa et al. (2017) reported an increasing performance of boys for 40 m sprint, while the performance of girls did not increase. However, in contrast to Tomkinson et al. (2018) for gender-specific differences, no clear direction was found overall. In the specific dimensions of PF, the strikingly similar results like Tomkinson et al. (2007) reported for power and speed cannot be concluded. For a detailed assessment of differences between male and female children and adolescents, a deeper statistical investigation must be performed, i.e., with a meta-analysis.

This review summarized data of studies in 16 countries from all continents and therefore estimates international trends of PF. With data from over 860,000 children and adolescents, the sample size is appropriate. This review was conducted following the PRISMA guidelines, making the approach systematic. Also, we developed a research protocol; for each of the included studies a quality assessment was performed to respect the strength of evidence (see Supplementary Material). However, registration of this review to record the process through a database such as PROSPERO was not made. Although there are several reviews examining trends in PF of children and adolescents, it does provide comprehensive work because it does not focus on one dimension of PF or separate aerobic and anaerobic performances. The review summarizes findings in all dimensions and extends to an actual global analysis, with studies having at least one measurement in or after 2006. The method of building subsamples and categorizing them is as detailed and specific as possible without generating a meta-analysis. However, this results in a different number of subsamples, depending on the variance of conducted tests, and leads to a weighting. The more subsamples built for a study, the stronger its weighted result.

Some methodological limitations of this review should be considered. There was only primary study research in one database of scientific evidences used to identify potential studies. Therefore, the review does not claim to be exhaustive, as gray literature or literature not published in English was not considered (e.g., Albrecht et al. (2016): MoMo Study for Germany). The primary studies used different methods and definitions, or there was large heterogeneity in the study population. The studies analysed data that differed substantially in methods and characteristics of samples and cohorts. The various sample sizes of different studies were not weighted, but influenced the representativeness of each study. Furthermore, the specific dimensions of PF were measured with different test items; sometimes test items even varied for a single dimension (e.g., seven different test items to measure endurance). No in-depth analyses of the primary data of the studies were made to summarize the results quantitatively by using statistical methods and calculated pooled-effect estimates. We assessed the reported trends dependent on the judgment of the authors in the respective studies. A meta-analysis would be desirable to report the relative change per year and to compare outcomes of studies with common metrics. Furthermore, such a meta-analysis allows determination of existing influences and their strength. This will help us find out whether a valid overall picture can still be obtained.

We considered gender, age, and BMI as relevant confounders of PF, but there are more; socio-economic status and geographical environment influence the trends in PF as well (Hanssen-Doose et al., 2021).

We did not include existing reviews reporting secular trends. A logical next step should be to conduct an umbrella review.

Conclusions

In conclusion, there is an overall declining trend when assessing the findings in PF of children and adolescents. However, these findings vary for the specific dimensions of PF and require specified and detailed reporting.

1.) For endurance, strength, and flexibility, the majority of the primary studies report a decline. This trend towards a deterioration appears to weaken in the more recent studies. The major changes in PF are more likely to be reported in work that goes back further in time (1960s until the 1980s)

2.) For speed and coordination, the same number of studies reported a decrease, increase or stagnation.

Gender- and age-specific differences for trends in PF are small, but changes seem to decrease for adolescents compared to children, and vary for gender in some dimensions without any clear direction. A standardized and regular monitoring of trends to design interventions and programs is needed. This monitoring should also include and report potential influencing factors such as gender, age, sociodemographic, and environmental differences. Furthermore, reporting of specific dimensions is indispensable. This monitoring is crucial to support PF as a resource for future health and as a requirement of an active lifestyle.

CHAPTER 3

The Potential of Data Pooling with MO|RE data

Slightly modified version of the submitted manuscript:

Eberhardt, T. Keller, K., Zimmermann, H., Schlenker, L., Bös, K. & Niessner, C. (submitted). The Potential of Data Pooling with Open Data Infrastructures in Motor Performance Research - A Discussion Based on the Example of MORE data. German Journal of Exercise and Sport Research.

Abstract

The rise of Open Science and Open Data had a significant impact on research practices, fostering collaborative and innovative approaches. To utilize Open Data, technical infrastructures are needed as instruments for management and access. Several repositories already exist for different disciplines, addressing the specific needs and requirements of the field. Despite the fact that motor performance data has a great potential for Open Data, it remains untapped. In order to fill this gap, the Institute of Sports and Sports Sciences at the Karlsruhe Institute of Technology has developed the repository MO|RE, funded by the German Research Foundation (DFG). It serves as an Open Data instrument and facilitates the pooling and sharing of motor performance data. This helps to overcome the existing challenges of sufficient large sample sizes within different settings and different groups.

This discussion explores the potential of data pooling with MO|RE data. We present the possibilities of the MO|RE data repository and highlight its role in addressing the specific needs of motor performance research, e.g. by ensuring data quality through a multi-stage review process and implementation of assigned metadata, MO|RE data enhances interoperability and reusability in line with the FAIR principles.

By using data pooling with MO|RE data, more comprehensive analyses of potential trends and changes, but also prevalence of motor performance in the population are possible. MO|RE data exemplifies how an Open Data infrastructure can overcome existing challenges in motor performance research and facilitate physical health goals through more robust and collaborative research.

Introduction

The increasing emphasis on Open Science and Open Data has revolutionized research practices in various disciplines, offering new opportunities for collaboration, transparency, and innovation. In order to realize this, technical requirements, such as supporting infrastructures have also been developed in recent years as a fundamental prerequisite for managing and opening research data (Büttner et al., 2011). In the field of sports science, particularly in research of motor performance, the potential of Open Data remains largely unexploited (Krüger et al., 2023). Research in motor performance is important, at it is a critical factor and resource for being physically active across the lifespan. An even more essential role is given to the development of motor performance in childhood and adolescence, because this level of proficiency set the foundation for an active and healthy lifestyle (Ortega et al., 2008). Lopes et al. (2020) outlined a number of points which are relevant for future research and knowledge in motor performance. They identified the need for collaborative action towards Open Data and emphasized their benefits. In addition, a survey within the sports science community showed the relevance for a specific data repository for researchers and practitioners, and reported an interest especially when own data in motor performance are generated (Kloe et al., 2019). However, despite its importance, so far there exists no explicit infrastructure to open data, that meets the specific needs of this research field.

To fill this gap, the Institute of Sports and Sport Science at the Karlsruhe Institute of Technology has established the MO|RE data repository (www.motor-research-data.de). Funded by the German Research Foundation (DFG), this open-access platform was designed to facilitate the sharing and pooling of motor performance data and to enable large-scale analyses and global monitoring (Lang et al., 2023). With the increasing recognition of the need for comprehensive, interoperable, but also specific and appropriate infrastructure, MO|RE data represents a pioneering effort of to integrate Open Data practices into sports sciences and enabling researchers to utilize the vast potential of collaborative data-driven research.

This discussion paper explores the potential of Data Pooling with an Open Data infrastructure, advancing further potentials of research in motor performance. We present the functions of MO|RE data and discuss the theoretical underpinnings, address the challenges, and outline the practical value.

For assessment of motor performance, specific test batteries and test items are used that make the latent construct measurable. A wide range of assessment tools of motor performance exists and no gold-standard has been yet established (Lopes et al., 2020). However, the amount of data of motor performance is huge and there are some standards and internationally distributed test items that are the most common ones. By pooling these data, sufficiently large samples and global monitoring of trends and prevalence in motor performance could be reached.

However, there must be an appropriate tool which provides a suitable solution, covering the specific needs. As an interdisciplinary research with heterogeneous practices and great potential for health, this the basis for further evidence. With MO|RE data, this urgent need has been at least initiated.

Idea of MO|REdata

Users of MO|RE data have two main functions: (1) Search and export of and (2) Upload and archive of research data. These functions are strongly related to the different roles of the user. A data provider has own data and wants to publish it within the repository. Whereas, the data user utilizes external data from MO|RE for further gain of research. Figure 1 illustrates this concept. The aim of MO|RE data was to focus on the specific needs and requirements of motor performance data to overcome the existing challenges, that inhibit Open Data in Sports Science and so far, may prevent to utilize the full potential and possibilities of these. To make MO|RE data useful and worthwhile, valuable and reliable datasets of motor performance must be available. They must contain relevant material for further research with common variables. We have put this into practice with different functions and adjustments, which are outlined and discussed below.

Figure 1. Idea of MO|RE data with the main functions for different roles of user (own illustration)

Functions of MO|RE data

To ensure interoperability and reuse, as two of the FAIR principles, standardization is an important factor, which we realized through the mapping and harmonisation process. To make MO|RE data appropriate and applicable, we identified the most common test items for motor performance internationally and created manuals to describe the standardisation in detail. The test items are implemented in MO|RE data and can be mapped to your own data when uploading a dataset. We have specified the format and unit of the test items and give the name and abbreviation. See Figure 2 for an overview of the identified test items within MO|RE data. With the harmonisation process, definition of a common vocabulary and exact meaning of data fields and attributes is addressed. This facilitates comparability and interoperability through consistency across different published datasets.

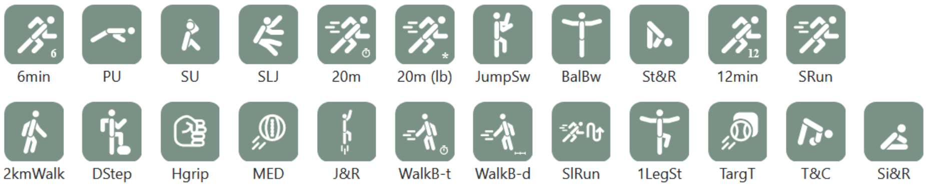

Figure 2. Test items in MO|RE data (www.motor-research-data.de)

Additionally, Quality check mechanisms are used to ensure that the published data are of high quality and data consistency. We have implemented a two-stage model for review, following the multi-dimensional approaches of Wang and Strong (1996). With an automated check by defined filters, the internal quality of accuracy, consistency, correctness, and credibility of the data is performed (Albrecht, Bös, et al., 2016). For data of motor performance this applies in particular to raw data and values in test items within a specified possible range. The filters check for impossible and implausible values for gender-specific age ranges and duplicates. As a manual implementation and independent source of quality control, the Editorial Board serves as a peer review instance. It evaluates the dataset as experts in the field and ensure a peer review process. Their focus is on the contextual and implementation quality, i.e. assessing the completeness of the metadata. They also check, whether the dataset is assessable through detailed and plausible description of data collection, processing and analysis.

A common requirement for Open Data is metadata. These provide essential information and description of the dataset. The documentation in the metadata is the foundation for organizing the data, understanding it and consequently processing it further. We have defined a detailed metadata standard structure based on the DataCite guidelines (DataCite Metadata Working Group, 2021). Different levels of metadata are implemented in MO|RE data, categorised as mandatory, recommended or optional. However, they ensure that information about the origin, structure and use of data is consistent and interoperable. For data of motor performance in particular, divergent implementations of test items and the data collection process are relevant for future interpretation and re-use. When collecting data using test items, standardisation is essential to ensure, data are collected with the same test protocol or processed in a common unit. It is also important to report the specific circumstances and relevant determinants within the assessment as precisely as possible, as these have a relevant influence on the data (Lopes et al., 2020).

If the dataset is accepted by the Editorial Board and published, the data and metadata get a persistent identifier. For MO|RE data, we obtain Digital Object Identifier (DOI) by the internal infrastructure RADAR4KIT which registers the identifier with DataCite. As the allocation of a DOI is already common practice for journal articles and books, the citation and reputation of datasets is becoming more common and growing. In terms of good scientific practice, all sources, materials, software, etc. should be cited used in the publication. The assignment of a globally unique and persistent DOI makes this even easier and automated. In addition , with the allocation of a DOI, research data and datasets as a citable product become increasingly important for the evaluation of scientific careers, as they can be clearly attributed (Pampel & Elger, 2021). Given the increasing pressure to publish, and in particular due to the enormous effort involved in collecting data of motor performance, there is less time for the elaborate methodological analyses and the writing of multiple articles that would be required for the variety of data (McKiernan et al., 2016). The data provider gains in importance for assessment and preparation of data with appreciated reputation and recognition also for published datasets.

So far, the main functions for data providers have been outlined. For data users, the search and export of motor performance research data is of particular interest. Due to the enormous effort and resources required to measure motor performance and to answer specific research questions in this field of sports science, the use of data from different samples and authors could offer a huge potential and expand the limited possibilities. With the main function of searching and exporting data, MO|RE data provides the basis for sharing and collaborating on datasets. Due to the often-required defined target group, or other specific characteristics specific to research in motor performance (e.g. age, socio-economic status), we have implemented a Search function. Various keywords and test items can be entered and combined to narrow down the search. Matching search hits are displayed by MO|RE data and provide an overview with some brief information about the data found and a reference to the respective metadata. The next step is to export datasets and their associated metadata. This function adresses the urgent need to pool data from different sources into one large dataset.

Theoretical Underpinnings

In the field of motor performance, Open Data holds immense potential for further innovative analyses across different populations. After data collection, processing, and analysis within the project and in order to realize Open data, it is crucial to not only publish the resulting publication itself, but also to mitigate the data into the public domain by making it accessible. This expands the value of the data by driving the research data lifecycle onwards and ensuring the re-use of data for further innovative analyses. This holistic research process can only be realised through the use of appropriate infrastructure (Rümpel, 2011). Figure 3 illustrates the location of MO|RE data within the research data lifecycle.

Figure 3. MO|RE data within the research data lifecycle (own illustration)

The tailored functions of MO|RE data described below in more detail are covering the FAIR data principles as well. The four principles findable, accessible, interoperable, and reusable ensure transparency and good scientific practice when implement Open Data (Wilkinson et al., 2016). They are a general guide for data management, but additionally for the tool development. With their consideration while implementation, a fairer Open Data practice is guaranteed (Betancort Cabrera et al., 2020). By adhering to the FAIR (Findable, Accessible, Interoperable, and Reusable) principles, Open Data initiatives in motor performance enable the pooling of diverse datasets and facilitating large-scale analyses that were previously unfeasible due to constraints in data. They serve as criteria and proof of a qualitative and deliberated initiatives. This approach not only enhances collaboration among researchers, but also improves the robustness and generalizability of findings.

Challenges

The legal and ethical requirements for Open Data in motor performance research are complex and relate to a variety of issues (Kreutzer & Lahmann, 2021). In assessment of motor performance, where health data are often collected, there is a significant challenge to maintain data privacy, but also to ensure data usability. In particular, when it comes to protecting sensitive data and involving children, compliance with regulations such as the General Data Protection Regulation for Europe and Germany is critical, requiring rigorous anonymization processes and careful management of data access. Furthermore, legal frameworks concerning copyrights vary widely for different levels of sharing, are various specific and less clarified. The working group “Sensitive Data in Sports Science”, which is part of the ad hoc committee “Research Data Management”, set up by the German Society for Sports Science, is working intensively on the issue of data protection and ownership and aims to develop clear recommendations for practical implementation.

Practical Implementations

The implementation of Open Data through specific infrastructures specifically motor performance research requires the development of further tools and methodologies, that address the unique needs of this field. The standardization of data collection protocols and the adoption if interoperable formats are essential to enable the seamless integration of data from different studies, thereby enhancing the ability to conduct meta-analyses and longitudinal studies with global comparisons. Other priorities, such as the development of universal health-related cut-points or normative values can be addressed through the repository and its specific functions. Internationally, the European Fitness Landscape is an example of the development of reference values from different datasets by pooling data in a more conservative way (Ortega et al., 2023). The repository based on large datasets and tailored variables as base can further ensure the assessment of reliability and validation of field-based fitness tests (Lang et al., 2023). Research of motor performance reaches its limits, particularly when it comes to observing trends and developments. Evidence is often limited to small samples, specific age groups and separated measurement points. With an adequate technical infrastructure, it is possible to pool different types of data to provides a comprehensive global monitoring and surveillance of motor performance. To take account of the multifaceted construct of motor performance, other variables and determinants can be included and set in contrast, as does the nationwide Report Card on Physical Activity for Children and Adolescents (Demetriou et al., 2024). But data pooling can also drive research forward with a more specialised look at different regions as the Fitness Barometer in the German federal state Baden-Württemberg (Eberhardt et al., 2021).

Current Efforts and Future Directions

In the context of motor performance, recent efforts within the German sports science community have made significant progress towards establishing Open Data practices with adequate infrastructures (Krüger et al., 2023). However, further steps need to be done to implement the practices as established and usual. The ad hoc committee on “Research Data Management” of the German Society for Sports Science (dvs) is developing concepts tailored to the needs of motor performance research, while MO|RE data as a central repository within the KonsortSWD consortium of the NFDI continues to develop and establish further functions.

The ability to access and analyse large datasets from multiple sources can reveal specific findings of trends, development, and levels of motor performance, providing a comprehensive view that individual studies may not be able to capture. As the field moves toward wider adoption of Open Data practices, the tools and infrastructures developed will play a critical role in advancing motor performance research and ultimately improving physical health outcomes across the lifespan. The MO|RE data repository, developed by the Institute of Sports and Sports

Science at the Karlsruhe Institute of Technology, is an example how an infrastructure for Open Data can address the specific needs and therefore support research of motor performance. By providing a user-friendly interface and robust features, MO|RE data encourages widespread adoption and fosters a culture of open, collaborative research.

CHAPTER 4

Changes in Physical Fitness during the COVID-19 Pandemic in German Children

Slightly modified version of the published paper:

Eberhardt, T., Bös, K., Niessner, C. (2022). Changes in Physical Fitness during the COVID-19 Pandemic in German Children. International Journal of Environmental Research and Public Health, 19(15): 9504. https://doi.org/10.3390/ijerph19159504

Abstract

With the beginning of the COVID-19 pandemic in December 2019, each country has developed strategies to try to control the virus. The restrictions and subsequent consequences also limited the possibilities and structures for being physically active. Therefore, the aim of this study was to examine changes in physical fitness in a cohort that was investigated over an extended period. Physical fitness testing was conducted with the IPPTP-R in a primary school from a small rural community annually since 2012. Mean values of test items were calculated for each cohort. We conducted an ANCOVA to examine the differences between cohorts PreCOVID and 2020 as the first year of the COVID-19 pandemic, and between PreCOVID and 2021 as the second year of the COVID-19 pandemic. Overall, no evidence for a negative effect of the COVID-19 pandemic on physical fitness in children between the ages of 7 and 9 years was found. In strength tests, performances increased when comparing the PreCOVID cohort and COVID-19 cohorts (Push-Ups: $p < 0.001$, $\eta p2 = 0.032$; $p = 0.017$, $\eta p2 = 0.006$). No evidence for a change was found for endurance (6-min Run: $p = 0.341$, $\eta p2 = 0.001$; $p = 0.267$, $\eta p2 = 0.001$. The rural community maintained physical fitness despite restrictions and limitations through the environmental circumstances. Considering this, it is a positive example of how adequate long-term efforts promoting physical fitness make an impact and an active friendly environment helps to overcome COVID-19 pandemics limiting the structures for being physically active.

Introduction

The importance of physical fitness for the healthy development of children and the positive influence for a lifelong active lifestyle are well-known and documented (Ortega et al., 2008; Robinson et al., 2015). The level of physical fitness predicts an individual's level of engaging in physical activity through given opportunities and limited capacities

(Lubans et al., 2010; Utesch et al., 2019). Physical fitness is the basis on which movement patterns are developed to be able to be physically active and, on the other hand, has a positive impact on psychosocial factors (Clark, 2002; Hänsel, 2008; Stiller et al., 2004; Utesch, Dreiskämper, Naul, et al., 2018).

Nevertheless, the levels of physical activity and physical fitness in youth have declined over the last decades, along with other variables influencing an active lifestyle. Since the beginning of the twenty-first century, physical fitness has been stagnating at a low level worldwide. Overall, children are less fit than those of former generations (Eberhardt et al., 2020; Fühner et al., 2021; Hanssen-Doose et al., 2021; Niessner, Hanssen-Doose, et al., 2020). Accordingly, the majority of children and adolescents do not meet the recommendations of the World Health Organization for daily physical activity (Finger et al., 2018; Woll et al., 2019). Sedentary behavior of children and adolescents has increased and screen-time exceeds recommendations (Greier et al., 2018; LeBlanc et al., 2017). As a consequence, the prevalence of obesity and overweight has steadily increased in past years, especially in younger children (Fang et al., 2019).

With the beginning of the COVID-19 pandemic in December 2019, each country has developed a strategy to try to control the virus. In Germany, the first officially registered case of COVID-19 appeared at the end of January 2020. Nationwide school closures and contact restrictions were implemented for the first time in March 2020, and again in December 2020 until March 2021 (Schilling et al., 2021). These restrictions also affected sports clubs, fitness centers, and the cancellation of all sports in schools, i.e., physical education lessons, extracurricular sports groups, or being active during breaks in the schoolyard. The COVID-19 pandemic and the subsequent consequences therefore not only limited social life, but also the possibilities and structures for being physically active.

There are studies that have examined the influence of the COVID-19 pandemic on physical activity (Rossi et al., 2021; Wunsch et al., 2022). A meta-analysis revealed a slightly negative global change in physical activity for children and adolescents (Wunsch et al., 2022). In Germany, the differentiated analysis of data from the Motorik–Modul (MoMo) study showed an increase of daily physical activity, such as playing outside or unstructured activities, during the first lockdown, but children could not maintain this level during the second lockdown (Schmidt, Burchartz, Kolb, Niessner, Oriwol, Hanssen-Doose, et al., 2021a). In contrast, the time spent in organized sports and overall physical activity decreased over the study period (Rossi et al., 2021; Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020; Schmidt, Burchartz, Kolb, Niessner, Oriwol, Hanssen-Doose, et al., 2021a).

There are also some studies that examined the influence of the COVID-19 pandemic and associated restrictions not only on physical activity, but also on the physical fitness construct (Basterfield et al., 2022; Chambonnière et al., 2021; Jarnig et al., 2021). Despite different measurement methods and study participants, the studies all reported a declining trend for endurance (Chambonnière et al., 2021; Jarnig et al., 2021; Wahl-Alexander & Camic, 2021). There appears to be less and inconclusive evidence for decreasing strength (Basterfield et al., 2022; Chambonnière et al., 2021). However, most of the studies have single measurement points before, during, or after the COVID-19 pandemic, but there is a lack of long-term monitoring. In our study, we conducted physical fitness testing in the same cohort over a period of eight years, plus 2020 and 2021, years in which the COVID-19 pandemic occurred. Therefore, these cohorts, which constitute the specific study population, provide the opportunity to draw conclusions based on a strong foundation of physical fitness data.

The aim of the study was to examine effects of the COVID-19 pandemic and changes in the different dimensions of physical fitness in a cohort that was investigated over an extended period.

Materials and Methods

This study used a cross-sectional cohort design with a population-based ad hoc sample. Overall, ten cohorts were followed yearly from 2012 until 2021. In the following, cohort always refers to the age group of 7–9-year-olds in the respective testing year. The International Physical Performance Test Profile—revised (IPPTP-R) was used to test the physical fitness in in the German federal state of Baden-Württemberg (Bös et al., 2021). All data presented in this paper were from children from a small rural community with fewer than 5000 inhabitants located in the northeast of Baden-Württemberg that participated in the test procedure over the entire period of ten years.

Physical Fitness

The IPPTP-R is an effective and validated physical fitness assessment tool developed to be conducted in practical settings (Bös et al., 2021). It is based on the approach of Bös and Mechling (1983) and the German Motor-Test 6–18 (Bös, 2016). It contains eight test items representing the five main dimensions of physical fitness endurance, strength, speed, coordination, and flexibility. Additionally, constitutional data including height, weight, and BMI were collected, and children’s age and sex, as well as test date and other characteristics of data collection were recorded. Table 1 shows the different test items. The detailed and precise description of the test items can be found in the existing manuals (Bös, 2016; Bös et al., 2021).

Table 1. Test items of the IPPTP-R

Dimension	*Test Item*	*Unit*
Endurance	*6 min Run*	*Meter*
Strength	*Standing Long Jump*	*Centimeters*
	Sit-Ups	*Number in 40 s*
	Push-Ups	*Number in 40 s*
Speed	*20 m Dash*	*Seconds*
Coordination	*Balancing Backwards*	*Number of steps*
	Jumping Sideways	*Number of jumps in 15 s*
Flexibility	*Stand and Reach*	*Centimeters*

Data Collection

The primary school in the community reported on here conducted the testing annually in October, except in 2020, when testing was limited due to the COVID-19 lockdown. Therefore, the 2020 tests were conducted in December. The teachers and volunteers were trained as multipliers using manuals, test material, and additional support and to execute the test tools. On a testing day, each child was tested in the school, sorted according to class. Parents provided informed consent forms through the primary school that conducted the testing. With informed consent, the test results were entered into the evaluation software and any personalized raw data on children’s physical fitness were pseudonymized initially and checked for quality. The dataset regarding this community was retrieved from the total dataset using postal code as variable of allocation. The extracted data were then analysed in a separate dataset.

Sample Description

As mentioned above, all data were from one community in the German state of Baden-Württemberg, which participated over the entire study period. Overall, 999 primary school children between the ages of 7 to 9 years (MV ± SD: age: 7.98 ± 0.82; weight: 29.0 ± 6.9 kg; height: 132.8 ± 7.5 cm) were included in the analysis. Among them, 55.6% (n = 555) were boys and 44.4% (n = 444) were girls. In the analysis, cohorts were compared to examine the effects and consequences of the COVID-19 pandemic on physical fitness levels. The different cohorts from the period between 2012 and 2019 were combined and considered representative of the physical fitness of children in the community before COVID-19. This cohort, called PreCOVID, comprised 801 children (MV ± SD: age: 7.97 ± 0.82; weight: 28.8 ± 7.0 kg; height: 132.7 ± 7.4 cm). The cohort from 2020, the first year of the COVID-19 pandemic, called COVID1, included 91 children in the analysis ([MV ± SD: age: 7.93 ± 0.87; weight: 28.9 ± 5.7 kg; height: 132.7 ± 7.8 cm). The cohort from 2021 (COVID2) included 107 children (MV ± SD: age: 8.08 ± 0.77; weight: 30.2 ± 7.1 kg; height: 133.4 ± 8.1 cm). The exact number of children according to cohort and gender is shown in Table 2.

Table 2. Distribution of the sample

Cohort	*Year of Measurement*	*Boys (n)*		*Girls (n)*		*Overall (n)*	
2012–2019 PreCOVID	*2012*	*57*	*n = 460 (57.4%)*	*44*	*n = 341 (42.6%)*	*101*	*n = 801 (100%)*
	2013	*62*		*39*		*101*	
	2014	*56*		*43*		*99*	
	2015	*39*		*28*		*67*	
	2016	*61*		*33*		*94*	
	2017	*57*		*45*		*102*	
	2018	*64*		*49*		*113*	
	2019	*64*		*60*		*124*	
2020 COVID1	*2020*	*43*	*n = 43 (47.3%)*	*48*	*n = 48 (52.7%)*	*91*	*n = 91 (100%)*
2021 COVID2	*2021*	*52*	*n = 52 (48.6%)*	*55*	*n = 55 (51.4%)*	*107*	*n = 107 (100%)*
	Overall	*555 (55.6%)*		*444 (44.4%)*		*n = 999 (100%)*	

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics 28 (IBM Corporation, Armonk, NY, USA). To obtain an overview of the distribution within the sample, frequency analyses and cross Tables were conducted.

Descriptive statistics with mean values and 95% CI were calculated for each test item and cohort overall and separately for boys and girls to reflect the entire measurement period. Missing data were not interpolated. The analysis was controlled for age and BMI. We conducted a univariate analysis of covariance (ANCOVA) to examine the differences between the cohorts PreCOVID and COVID1, and between PreCOVID and COVID2 adjusted for gender. The PreCOVID cohort value was formed using the mean value of individual cohorts from 2012–2019. The level of significance was set at $p < 0.05$. Effects were assessed with partial eta squared (ηp2). Pairwise comparisons with Bonferroni correction were performed to determine differences between the cohorts.

Results

Overall, 999 primary school children aged 7 to 9 years from a small rural community in the German state of Baden-Württemberg were included in the study

(PreCOVID n = 801; COVID1: n = 91; COVID2: n = 107). There were no significant differences for age and BMI between the ten cohorts, but gender-specific differences in mean values in the test items.

Figure 1 shows the trends in test items for all measurement years overall and separately by gender (see Table A1).

There was a linear, consistent level of performance for the 20 m dash through 2017 in boys and girls. In 2018, an increase was observed for either gender, and this level of speed remained stable until the last measurement in 2021. The ANCOVA for the test item 20 m dash revealed that children in the cohort COVID1 were 0.20 s slower than in the PreCOVID cohort ($F(1,859) = 15.89$; $p < 0.001$; $\eta p2 = 0.018$). The comparison with cohort COVID2 showed a significant difference of 0.23 s ($F(1,861) = 18.69$; $p < 0.001$; $\eta p2 = 0.021$). The influence of the covariate gender was significant for both ANCOVAs ($p < 0.001$; $p < 0.001$).

The analysis of the test item balancing backwards showed an opposite gender-specific trend until 2015, followed by a peak in 2016 for both boys and girls. This increase stopped abruptly and tended to remain stable until 2019. No significant difference was found in the ANCOVA, with 0.22 steps between cohort PreCOVID and COVID1 ($F(1,874) = 0.06$; $p = 0.813$; $\eta p2 = 0.000$). However, children in cohort COVID2 performed 2.03 steps better than cohort PreCOVID ($F(1,893) = 5.67$; $p = 0.017$; $\eta p2 = 0.006$). The covariate gender had no significant influence on the analysis ($p = 0.232$; $p = 0.215$).

The mean values for jumping sideways revealed no trend. There were ups and downs through all cohorts, with a peak in 2020 and a minimum of performance in 2012 and 2017. There were inverse performance levels for boys and girls for the cohorts 2014 through 2016. Analysing the differences for the test item jumping sideways showed that there was a difference of 4.32 fewer steps in PreCOVID compared with COVID1 ($F(1,874) = 27.05$; $p < 0.001$; $\eta p2 = 0.030$). There was no significant difference found between PreCOVID and COVID2, with 1.24 fewer steps measured for PreCOVID ($F(1,892) = 2.71$; $p = 0.100$; $\eta p2 = 0.003$). The influence of the covariate gender was not significant ($p = 0.423$; $p = 0.353$).

A steadily declining trend was found for the test item stand and reach, with its minimum in 2018. The level of flexibility subsequently increased. This development was found for boys and girls equally, but with clear differences in the measured values. The ANCOVA revealed 0.88 cm more in COVID1 than in cohort PreCOVID, but the difference was not significant ($F(1,871) = 1.44$; $p = 0.230$; $\eta p2 = 0.002$). PreCOVID had 1.00 cm less for stand and reach than COVID2, but this difference was also not significant ($F(1,888) = 2.16$; $p = 0.142$; $\eta p2 = 0.002$). The covariate was statistically significant in both cohort comparisons ($p < 0.001$; $p < 0.001$).

Push-up performance was consistent over the cohorts before increasing in 2017 and peaking in 2019. A significant difference was found in COVID1 with 2.29 more performed push-ups compared with PreCOVID ($F(1,875) = 28.63$; $p < 0.001$; $\eta p2 = 0.032$). There was a significant positive difference between PreCOVID and COVID2 of 0.94 ($F(1,892) = 5.69$; $p = 0.017$; $\eta p2 = 0.006$). The covariate gender had no significant influence on either ANCOVA ($p = 0.855$; $p = 0.924$).

The test item sit-ups improved consistently, but showed an apparent reversal in gender-specific performance for 2014 and the highest levels up to 2019. Analysing cohort differences with the ANCOVA, the performance differed significantly with 1.95 more sit-ups in COVID1 than in PreCOVID ($F(1,863) = 9.87$; $p = 0.002$; $\eta p2 = 0.011$). In addition, with 1.36 more sit-ups, COVID2 was significantly better than PreCOVID ($F(1,881) = 5.50$; $p = 0.019$; $\eta p2 = 0.006$). The covariate gender had a significant influence on the differences ($p < 0.001$; $p < 0.001$).

For standing long jump, initial measurements already showed significant differences between boys and girls. This difference was found for all cohorts with no apparent trend. However, the analysis revealed that children in COVID1 jumped 7.24 cm farther than children in PreCOVID ($F(1,873) = 11.13$; $p < 0.001$; $\eta p2 = 0.013$). However, the comparison between PreCOVID and COVID2 showed no significant difference, with 0.56 cm more for COVID2 ($F(1,890) = 0.08$; $p = 0.782$; $\eta p2 = 0.000$). The covariate gender was statistically significant for both cohort comparisons ($p < 0.001$; $p < 0.001$).

The mean values for 6 min run in the 2012 cohort differed significantly for boys and girls. Performance differed by gender over the measurement period, but the development of the overall sample revealed no trend. No significant differences were found between COVID1 and PreCOVID for the 6 min run, with COVID1 running only 15.31 m more than PreCOVID ($F(1,857) = 0.91$; $p = 0.341$; $\eta p2 = 0.001$). The children in PreCOVID ran 16.94 m less than COVID2, but these differences were also not significant ($F(1,866) = 1.23$; $p = 0.267$; $\eta p2 = 0.001$). The covariate gender had a significant influence on the measured differences ($p < 0.001$; $p < 0.001$). See Tables A2 and A3 for the adjusted mean values of the ANCOVA in each test item and cohort.

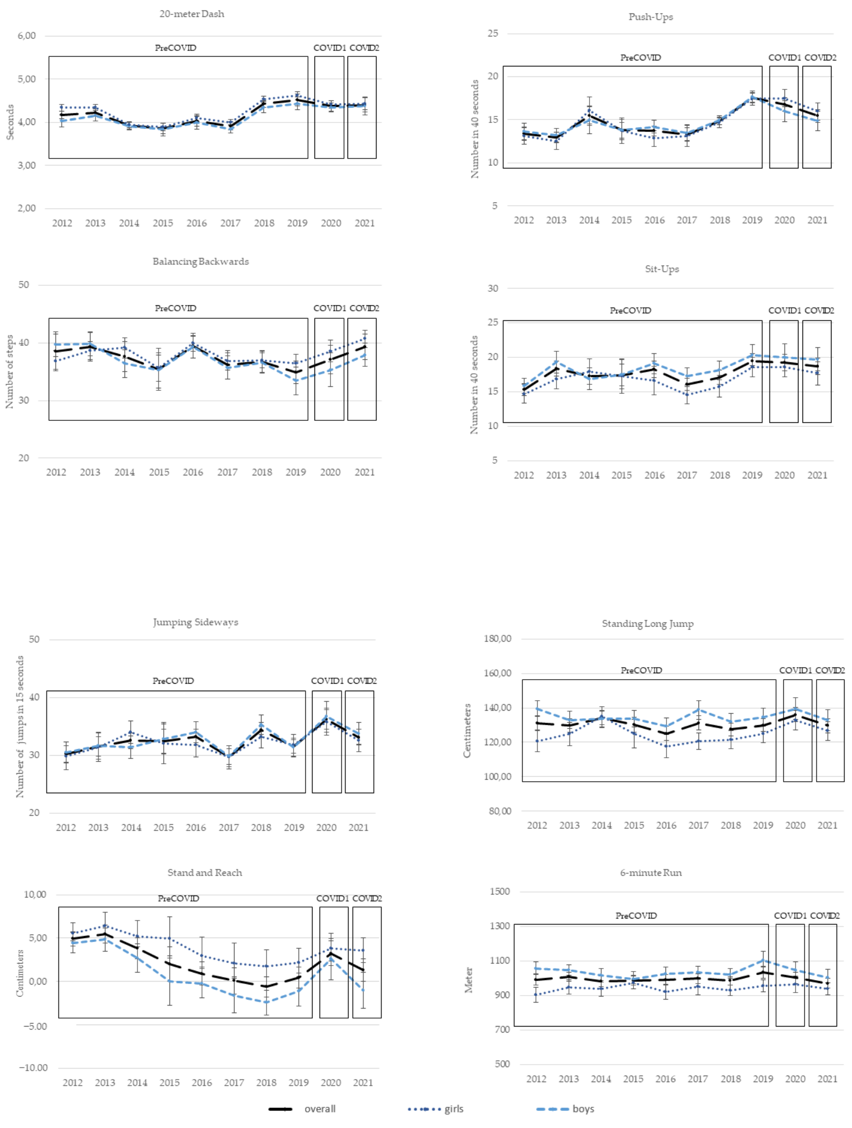

Figure 1. Trends for test items over each year of measurement overall, and for boys and girls separately

Discussion

The aim of the study was to examine COVID-19 effects on the physical fitness of primary school children in a rural community in Baden-Württemberg with fewer than 5000 inhabitants.

We conducted measurements over a long-term period and therefore have strong evidence for the overall levels and changes of physical fitness in the sample.

Summary and Evaluation of the Results

For the test item 20 m dash, the statistically significant differences had no practical relevance. Speed levels remained stable in the COVID-19 cohorts. Comparing the results for balancing backwards, we see that the previously constant performance increased in the measurement for COVID2, but remained the same in COVID1. In addition, representing the dimension coordination, jumping sideways also had a peak in COVID1, but the same stable level before and after. Thus, no evidence for an effect was found. Pombo et al. (Pombo et al., 2021) also reported no inferior results for jumping sideways in 6–9-year-old Portuguese children tested before and after the COVID-19 lockdown. However, from December 2019 to September 2020, there was an overall general trend of shifting to a lower quartile (Pombo et al., 2021). An increase in children's performance categorized as "very low" in the 20 m shuttle run was also observed by Basterfield et al. for participants in a primary school in England (Basterfield et al., 2022). Flexibility performance in the stand-and-reach test did not differ significantly between the three cohorts. The rising trend of recent years was not stopped by the pandemic. In contrast, there was a negative effect in the study in England, which measured a decrease of 1.8 cm between October 2019 and November 2020 for 8–10-year-old children (Basterfield et al., 2022).

The number of performed push-ups was significantly higher in both COVID cohorts compared to the overall 2012–2019 pre-pandemic cohort, which was also reflected in the results of the sit-ups test. There was no evidence that upper body strength levels were influenced negatively by COVID-19 restrictions and consequences. While Wahl-Alexander and Camic (2021) found a decrease of 35.6% for push-ups and 19.4% for sit-ups in children with a mean age of 9.6 years between summer 2019 and 2020, other results are consistent with our findings. The same was found for leg strength, which was measured using the standing long jump test. Performance levels increased significantly in the COVID1 cohort, but then remained stable again compared to the PreCOVID cohort, and showed no evidence of negative effects. Basterfield et al. (2022) and Wessely et al. (2022) also reported a performance increase for standing long jump. This suggests that strength is more resilient to negative effects of COVID-19 than other dimensions of physical fitness (Basterfield et al., 2022). However, Chambonnière et al. (2021) measured the standing long jump performance of 3rd and 4th graders in France for the period between 2020 and 2021 and found a decrease of 34.7 cm. This is consistent with another study examining the same age between 2019 and 2020 (Pombo et al., 2021).

The analysis for endurance revealed no significant difference between the cohorts and no effect of the COVID-19 pandemic. The performance levels for the 6 min run were stable across the measured cohorts. Other studies that analysed endurance found different effects (Basterfield et al., 2022; Jarnig et al., 2021; Pombo et al., 2021; Wahl-Alexander & Camic, 2021). Jarnig et al. (Jarnig et al., 2021), who also implemented the 6 min run, reported a decrease of 102 m in children aged 7-to-10 years old between September 2019 and September 2020 (Jarnig et al., 2021). Two other studies performed the 20 m shuttle run to measure effects for endurance and reported 2.39 (Chambonnière et al., 2021) and 3 (Basterfield et al., 2022) fewer shuttles in their second measurement point.

Explanation Approaches

Overall, our results show no evidence for a negative effect of the COVID-19 pandemic on physical fitness in children between the ages of 7 and 9 years, but changes varied for the different test items and dimensions. Especially, performances of the COVID cohorts in test items for strength increased. It seems that alternative options of exercising physical fitness like online and indoor workouts mitigate some effects of COVID-19 pandemic. However, due to the restrictions and closures of organized forms in sports clubs or schools, we conclude that dimensions where high intensities and stimuli are needed could not benefit. This could suggest the relevant role of physical activity with peers and within an institution to maintain a global and comprehensive development in all dimensions of physical fitness.

When classifying the data into gender and age-specific percentiles of a nationwide reference sample, the children in this specific community represent a very high level of physical fitness above the average (Kloe, Oriwol, et al., 2020; Niessner, Utesch, et al., 2020). The community has various specific initiatives and commitments to promote physical activity. For example, the primary school curriculum emphasizes the importance of physical fitness and appropriate promotion is determined in the preamble. The community is also a part of the project “Bewegte Kommune-Kinder” which aims to enable a sufficient and adequate development of physical fitness for all children in the community. It seems that children who had higher levels of physical fitness before COVID-19 are more resilient with regard to restrictions and limitations affecting physical activity. Similarly, Jarnig et al. (2021) reported that children who were members of sports clubs had better cardiorespiratory fitness measures at all time points. However, a higher level in the beginning leads to a higher level after the pandemic (Jarnig et al., 2021). Adequate levels of physical fitness appear to increase resilience to limited physical activity due to external circumstances, such as the lockdowns during the COVID-19 pandemic.

Furthermore, there is evidence that total physical activity did not decline globally during the COVID-19 pandemic but that the form of being physically active changed (Schmidt, Burchartz, Kolb, Niessner, Oriwol, Hanssen-Doose, et al., 2021a; Schmidt, Burchartz, Kolb, Niessner, Oriwol, & Woll, 2021; Wunsch et al., 2022). While organized physical activity decreased, time spent in habitual physical activity and unstructured forms such as playing outside increased (Rossi et al., 2021; Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020; Schmidt, Burchartz, Kolb, Niessner, Oriwol, & Woll, 2021). Schmidt et al. (Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020) found an increase from 75 min per day before the COVID-19 pandemic to 105 min per day playing outside during lockdown in spring 2020 for 6-to-10-year-old children in Germany. Most notably, socioeconomic background and place of residence are influencing determinants of levels of physical activity and physical fitness (Rossi et al., 2021; Schmidt, Burchartz, Kolb, Niessner, Oriwol, & Woll, 2021; Wessely et al., 2022; Wunsch et al., 2022). We also analysed physical activity changes in our sample and can confirm these findings. Children indicated that they spent less minutes for physical activity in sports clubs, while time for physical activity in leisure time increased during the COVID-19 pandemic (Betz, 2022).

Wessely et al. [32] reported decreasing results for measurements of physical fitness during the COVID-19 pandemic, whereby children with a high social burden showed lower performance levels. Children with low socioeconomic status also showed lower levels of physical activity, but the home and living environment had a particular influence (Rossi et al., 2021; Wunsch et al., 2022). In our study, we have no data on socioeconomic status of the study subjects, but we consider community structure data. The community has less than 5000 inhabitants and is located in the north-east of Baden-Württemberg in Germany. The environment is known as rural with access to green areas and playgrounds. For the children in this community, the environment might have provided easy opportunities to be physically active during the COVID-19 pandemic and thus possibly prevented a negative effect on physical fitness. For rural children, the impact of COVID-19 policies and restrictions was limited, but results may differ in urban children. Asked with whom they were physically active, more children in this community named their parents, when restrictions were issued (Betz, 2022).

Limitations

There are limitations regarding sample and selection bias since we investigated an ad hoc sample with a cross-sectional cohort design of children from one primary school in a rural community of the German federal state Baden-Württemberg. The sample is not representative and its results show a selection effect concerning a higher physical activity and fitness compared with the whole of Germany. However, the long study period and the number of cohort measurements before and during the COVID-19 pandemic ensure that children's physical fitness is considered globally and not just a one-point statement based on a one-point measurement.

Moreover, in this study were some confounding factors, e.g., socio-economic status, educational level of parents, and level of testosterone, which may affect the results, but were not controlled. However, we can use some physical activity data to classify. For future investigations, the methodology should be improved and possible cofounding data collected.

Practical Implications

The results showed that this particular community, which has been testing and supplementing physical fitness promotion with additional projects for ten years, has an above-average level of physical fitness. The data thus suggest that a variety of long-term physical fitness programs really do help a lot when it comes to promoting an active and healthy lifestyle. The programs should be anchored sustainably in the community and target people's behavior and the conditions. Because not every child had the same opportunities to be physically active (Schilling et al., 2021; Wessely et al., 2022), especially in times when restrictions and limitations influence regular and structured physical activity, policy makers, communities, and other relevant stakeholders must provide children with access to environments that are conducive to and supportive of physical activity. Parents should operate as role models for an active lifestyle. Further research needs to examine larger cohort data to determine generalizable effects of the COVID-19 pandemic on physical fitness in children. In addition, these cohorts need to be monitored for additional years to establish long-term effects and influences. Pooling data, for example with the MO|RE data repository, from many small samples tested with a uniform and standardized measurement tool helps provide a wide range of participants and increases the comparability of findings across studies (Kloe et al., 2019).

Conclusions

In conclusion, this study examined effects of the COVID-19 pandemic and changes in various dimensions of physical fitness in a cohort investigated over a long-term period of ten years. We found no evidence for an overall negative effect, but results differed between test items and dimensions. The rural community presented in this study is well aware of the importance of physical fitness. Physical fitness was maintained despite restrictions and limitations through the environmental circumstances. Considering this, this sample is a positive example of maintaining physical fitness throughout the COVID-19 pandemic. Adequate interventions and long-term efforts make an impact, but should address each child.

CHAPTER 5

Secular Trends of Children´s Physical Fitness and COVID-Pandemic Impact

Slightly modified version of the submitted manuscript:

Eberhardt, T., Bös, K., Woll, A., Kliegl, R. & Niessner, C. (submitted). Secular Trends of Children´s Physical Fitness and COVID-Pandemic Impact for Years 2012 to 2022. Sports Medicine – Open.

Abstract

Physical Fitness is a key component for the development of an active lifestyle and a determinant of future health, particularly in childhood. The assessment of physical fitness enables the reporting of findings that allow evidence-based monitoring and the identification of long-term trends. The COVID-19 pandemic is an additional factor to be considered in the analyses as its influence is already known. The aim of these analyses was to investigate secular trends in children´s physical fitness comprehensively before and during the pandemic.

Data from annual assessments in the German federal state of Baden-Wuerttemberg from 11 cohorts since 2012 were pooled, resulting in 29,855 children (7.07±1.62 years, 14,749 girls) included in the analyses. We estimated the effects of the COVID-19 pandemic using a regression discontinuity design within a linear mixed model to estimate pre-pandemic and pandemic trends, and to adjust for relevant factors.

For the pre-pandemic cohorts, we found significant trends in six test items, but these were slightly negative or positive. This suggests a recent slowing of the declining trend in physical fitness in children. The COVID-19 pandemic affected physical fitness as pandemic trends changed into negative at the critical date. There was no evidence of pandemic changes in coordination. The effects of age, sex, and body constitution varied, but their potential to influence physical fitness was underlined.

Continuous monitoring of physical fitness in children is essential, especially in the context of the COVID-19 pandemic. It identifies trends and changes and provides evidence for action against. In particular, it is important to initiate systematic initiatives during childhood to promote physical fitness and reduce deficits as this is the time when the foundations for an active and healthy lifestyle are laid.

Introduction

Physical Fitness (PF) is composed of multiple items, which reflects the ability to perform physical activity or physical exercise (Ortega et al., 2008). According to Caspersen et al. (1985), PF can be categorized into health- and skill-related items. In Germany, the most common used definition by Bös and Mechling (1983) is based on this concept, too. It distinguishes five main dimensions of PF: endurance, strength, speed, coordination, and flexibility as an additional passive dimension. These latent abilities are measurable and apparent through PF assessment with different test items. For a development of a healthy and active lifestyle, PF is one of the fundamental determinants (Ortega et al., 2008). Acquired PF in childhood is the base on which more specific motor competencies and movement patterns were developed (Stodden et al., 2008). It enables children to be physically active, also later in life and thus to prevent negative health outcomes (Jaakkola et al., 2016; Robinson et al., 2015; Ruiz et al., 2009). Likewise, findings suggest that cardiorespiratory fitness, muscular fitness and muscular endurance have moderate stability over the lifespan (Fraser et al., 2021; García-Hermoso et al., 2022). An improved level of cardiorespiratory fitness reduces the risk of cardiometabolic diseases later in life and future disability (García-Hermoso et al., 2022; Henriksson et al., 2021). Higher muscular fitness is associated with lower risk of obesity, adiposity deposition and skeletal health (García-Hermoso et al., 2019; Rodrigues et al., 2013; Smith et al., 2014). Moreover, the function of PF as marker of health extends to cognitive and psychological benefits (Cadenas-Sanchez et al., 2021; Gu et al., 2019; Sardinha et al., 2016).

Given the link to this health-related focus on PF and especially with its need of a fundamental development in childhood, assessment of PF in children is crucial. It enables to present evidence-based surveillance and provides insight into the youth populations PF level. Thereby, even more essential is a long-term monitoring so that PF changes and trends are detected and results can be analysed in contrast to previous and further findings (Lang et al., 2023). There exists already evidence on secular trends for the past decades and the literature stated declines in PF of children. Tomkinson (2007) and Tomkinson and Olds (2007c) summarized the recent findings for aerobic and anaerobic fitness between 1958 and 2003 and included data of over 50,000,000 children aged 6-19 years. Aerobic performance decreased of -0.36% per annum over the entire measurement period. In more detail, the decline started after a cross-over point from improvements to the negative trend in 1970. An update on secular trends in cardiorespiratory endurance with a meta-analysis of data on the 20m-shutle run test revealed, that the decline in endurance slowed and stabilized since 2000 (Tomkinson et al., 2019) This goes in line with another review analysing national trends in all dimensions of PF and with findings from national data of the MoMo-study in Germany, describing a plateauing in level of endurance from 2003 to 2017 (Hanssen-Doose et al., 2021). A meta-analysis of Fühner et al. (2021) attributed cardiorespiratory endurance to have the largest effects of the different dimensions of PF in declining secular trends since 1986, but to stabilize since 2010. Findings for anaerobic performances, operationalized with speed, muscular power and strength tests, tend to be smaller relative to secular changes in aerobic fitness (Fühner et al., 2021; Tomkinson, 2007). The global pattern of change was comparatively consistent and stable worldwide between 1958 and 2003 (Tomkinson, 2007). For the performance in standing long jump, representing leg strength, similar results were reported currently by Tomkinson et al. (2021). Even if a declining trend was found from 2000 onwards, the improvements since 1960 has been overall negligible per decade. This finding is also reported for relative muscle strength as the magnitude of the secular trends is small and range consistently (Fühner et al., 2021). Nationally, results of the MoMo-study were analysed for population-based trends in PF comparing three measurement time periods. Overall, the study revealed positive trends between baseline (2003-2006) and wave 1 (2009-2012), but a stagnation between wave 1 and wave 2 (2014-2017). The remaining plateauing appeared in strength, speed, and coordination in the group aged 4-17 years (Albrecht, Hanssen-Doose, et al., 2016; Hanssen-Doose et al., 2021). Overall, for trends of PF national and international research stated a “stagnation of PF on a low level” (Eberhardt et al., 2020; Niessner, Hanssen-Doose, et al., 2020).

The spread of the COVID pandemic since 2020 affected the life and circumstances of children. Already some studies exist that examined the influence. The limitations imposed by lockdowns and school closures have disrupted daily routines, reduced opportunities for physical activity and social interaction. Recent studies indicate significant changes in children's mental health issues such as anxiety and depression (Ravens-Sieberer et al., 2022). The COVID pandemic and associated restrictions notably impacted activity behaviour in Germany as research highlights a marked decrease in physical activity and an increase in media consumption among children (Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020). Consequently, these changes also might have a substantial impact on children's PF. Several studies examined this in the recent years since COVID pandemic occurred. Most of them compare two measurement time points or periods before and after the pandemic. Especially, for endurance declines were found after COVID pandemic in several studies over Europe and Asia (Chambonnière et al., 2021; Drenowatz et al., 2023; Eberhardt et al., 2022; Giuriato et al., 2023; E.-J. Lee et al., 2022; Martinko et al., 2023). Teich et al. (2023) report changes for all six tested dimensions of PF and a decreased performance in the tests for endurance, speed and coordination, which particularly involves running. They classified pre-pandemic cohorts 2016-2019 and pandemic cohorts 2020-2022 and benefited from annual testing since 2016 in third grades of Brandenburg. This enabled them to detect secular trends over the period and consider COVID pandemic influences. Martinko et al. (2023) also found dropping levels of PF, but differentiate between weight status of children and report smaller decrease in obese children.

However, to detect secular trends with monitoring and considering concerned groups and particular situations and hotspots, there is a need of homogeneity and specificity in various aspects of surveillance (Lang et al., 2023). The evidence suggests to identify country-specific trends and further differentiated results for varying age-groups and specific dimensions of PF. Only a few studies exist with a sufficient large sample size and uniform sample, continuous measuring points, and a standardized assessment of PF with the same test profiles over years. Therefore, the aim of this paper was to examine secular trends in PF of children since 2012 over a 10-year period, using uniform measurement methods and designs. We analysed the different dimensions of PF separately with standardized test items. Because the COVID-pandemic had a significant impact on children's life and, consequently, on PF, the secular trend was modelled with regard to this particular influencing factor.

Methods

Study design

The data presented in this paper are drawn from the project entitled "Fitnessbarometer" in cooperation with the Kinderturnstiftung of Baden-Wuerttemberg and therefore the sample is limited on this federal state of Germany. Data of PF was collected from 2012 until 2022 with the test profiles German Motor Test 6–18 (GMT 6–18) and KITT+ 3–10, based on the dimension-oriented approach (Bös et al., 2020b, 2020a, 2023). The testing of PF was conducted through multipliers, who were practitioners (e.g. teacher, educators, coaches). They were trained with the help of material and additional scientific support. After assessment, they entered the data into an evaluation software. The authors received the raw data pseudonymized per year and uploaded it into MO|RE data, a sports specific e-research infrastructure (www.motor-research-data.de, Karlsruhe Institute of Technology, 2023). For these analyses, data pooling was used to merge the individual cohorts into one large data set comprising all cohorts from 2012 until 2022. Therefore, the paper used a cross-sectional cohort design with a population-based ad hoc sample (Bös & Kinderturnstiftung Baden-Württemberg, 2023e, 2023f, 2023d, 2023c, 2023b, 2023a, 2023g, 2023h, 2023h, 2023i)

Physical Fitness Tests

PF was measured with the German Motor Test (GMT) and the similar Kinderturntest Plus (Bös et al., 2020b, 2020a, 2023). The test profile is based on the dimension-oriented approach and assesses the latent dimensions of PF on a measurable skill level, operationalized with the test items 6-minute Run, 20-m Sprint, Standing Long Jump, Push-Up, Sit-Up, Jumping sideways, Balancing backwards and Stand-and-Reach. Each test item represents at least one cell of the taxonomy of tests. See Table 1 for the specific categorization within the taxonomy with task structure. Note that four test items (i.e., Standing Long Jump, Jumping sideways, Balancing backwards and Stand-and-Reach) were assessed for 3–10 year-old children aged; the other four test items (i.e., 6-minute Run, 20-m Sprint, Sit-Ups and Push-Ups) were assessed for 6–10 year-old children. Additionally, constitutional data with height and weight were collected. The detailed description of the individual test items can be found in the test manuals.

Table 1. Taxonomy with Task structure and Test Items of the GMT (modified by Bös et al., 2023)

Structure of Task		***Motor Dimension***				***Passive Systems of Energy Transfer***
		Endurance	*Strength*	*Speed*	*Coordination*	*Flexibility*
Locomotor Movements	*Walking, Running*	*6-minute Run*		*20-m Sprint*	*Balancing backwards*	
	Jumping		*Standing Long Jump*		*Jumping sideways*	
Movements of Body parts	*Upper Extremities*		*Push-Up*			
	Trunk		*Sit-Up*			*Stand-and Reach*

Data Processing

For data pre-processing and post-processing (i.e., construction of tables and figures) we used the R programming language (R Core Team, 2023) in the RStudio IDE, primarily packages tidyverse (Lüdecke et al., 2022) and easystats (Lüdecke et al., 2022).

For a better understanding, we transformed data so that larger values implicate better performance within the test. For that reason, the 20-m Sprint score was converted to a speed score (i.e., 20/time). Separately for boys and girls, test scores outside of a ± 3 SD range were excluded. This left us with 194,360 test scores from 29,855 children for the analyses. Finally, test scores were computed to z-scores to facilitate comparisons between tests, sex, and age effects. See Table 2 for detailed descriptions of cohorts.

Over the entire 10-year period, 30,255 children aged 3-10 years and from 11 cohorts (2012 until 2022) were tested. We excluded children with missing values of postal code, mass or height and include only children with a BMI range from 10 to 45. We used the ext_bmiz function of the R package growthcleanr (Daymont et al., 2017) to convert raw scores of mass, height, and BMI [i.e., mass (kg)/height (m2)] to age- and sex-adjusted extended BMIz and the CDC LMS z-scores from CDC growth charts (Hales et al., 2022). The extended values differ only for children with a BMI > 95th percentile. Linear and quadratic terms for these z-scores were included as covariates in linear mixed models (LMMs) for statistical inference. LMM fits and comparisons were carried out in the Julia Programming Language (Bezanson et al., 2017) with the MixedModels.jl package (Alday et al., 2024; Bates et al., 2024); partial-fitted effects were computed with MixedModelsExtras.jl package (Alday, 2024).

Table 2. Detailed Description of Sample

Measurement	***Number of children***	***Number of events***	***Number of observations***
Pre-pandemic 2012-2020	*23,581*		*154,181*
Pandemic (2021-2022)	*6,293*		*40,179*
Total	*29,855*	*1,312*	*194,360*

Regression Discontinuity Design (RDD)

Data was collected from nine pre-pandemic cohorts from 2012 to 2020, and two pandemic cohorts in 2021 and 2022. We used the COVID pandemic as a quasi-experiment and integrated it into the LMM. The RDD provides statistics, which refer to a critical date and thus for a possible pandemic effect (Lee & Lemieux, 2010; Thistlewaite & Campbell, 2017). We set the critical date at 2020-12-31 and dummy coded a pre-pandemic and pandemic cohort variable. Test dates were centered at the critical date. For pre-pandemic years, i.e. 2012 to 2020, we used the middle of the year as test dates; for the years of COVID pandemic (2021 to 2022), the specific month of testing was also available and included to increase precision of estimates for 2021–2022 trends. The implementation of the RDD allowed us to estimate linear pre-pandemic and pandemic slopes and their intercepts at the critical date. The difference between the intercepts estimates the size of the pandemic effect at the critical date. The difference between the pre-pandemic and pandemic regression slopes is tested with the interaction of test date with a 0/1-dummy variable coding pre-pandemic vs. pandemic dates. Thus, significant interactions indicate that trends across years differed before and after the criterion date, that is that the COVID-pandemic affected the secular trends. Obviously, this is a quasi-experimental approach, and we do not know what the secular trends would have been without the COVID pandemic.

Linear Mixed Model Selection

Starting with an expanded version of an LMM reported by Bähr et al. (2024), we followed recommendations of Bates et al. (2018) and Matuschek et al. (2017) for selection of a RES that was not overparameterized, meaning that (a) the variance-covariance matrix of random-effect terms was not singular and (b) a principal component analysis of matrix showed unique variance for all VCs. Further selection of terms was based on the AIC criterion when terms under consideration were theoretically motivated and on BIC otherwise.

The RES of the most complex LMM contained VCs and CPs for the eight test scores for the two random factors Child (n=29,855) and PLZ (i.e., zip code of assessment location; n=232). For the random factor PLZ, we also included VCs and CPs for effects of COVID at the critical date, pre-pandemic slope, the change from pre-pandemic to pandemic slope, sex, and linear trends for age and BMI-SDS. The fixed-effect part of the LMM comprised for each item (a) three parameters for COVID-pandemic and cohort effects as a RDD with 2022-12-31 as the critical date (i.e., pre-pandemic and pandemic slopes and the difference of these linear regression lines at the critical data), (b) four parameters for sex, linear and quadratic age, and the interaction between sex and linear age, (c) eight parameters for body constitution (i.e., linear and quadratic trends for mass, height, and BMI-SDS, (d) interactions of sex with linear and quadratic trends for BMI-SDS), and (d) one parameter for test. This complex LMM was overparameterized because the PLZ-related VC for BMI-SDS was very close to zero and the PLZ-related CP for COVID and pre-pandemic slope was > .93. Also, PLZ-related CPS for pre-pandemic slope, change to pandemic slope, age, and sex were very small. Dropping the PLZ-related VC for BMI-SDS and PLZ-related CPs, except for test items and COVID effect, led to a parsimonious LMM supported by the data. The RES of the parsimonious LMM specified 86 model parameters.

In the fixed-effect part, main-effect and interaction terms were kept for all test items when they were significant on one of them. Conversely, terms that were not significant for any of the tests were removed unless they belonged to the core of the theoretical foci (i.e., cohort/COVID, sex, age, and body constitution). This was only the case for the quadratic trend of height and marginally also for the quadratic trend of sex and BMI-SDS. We kept the latter for theoretical reasons (see Bähr et al., 2024). Removing other quadratic model terms significantly decreased the goodness of fit according to the AIC. yielding at total of 15 x 8 = 120 fixed-effect parameters. Thus, the total number of model parameters (i.e., number of model degrees of freedom) for the parsimonious LMM was 86+120=206. Its number of effective residual degrees of freedom was 97,482 (i.e., computed as the difference between the number of observations and the number geometric degrees of freedom that account for the loss of information due to correlations between Child and PLZ random effects). The effective number of degrees of freedom is considerably smaller than what might be expected given 194,360 observations and 206 model parameters but model fit is still based on about 423 observations per model parameter.

Results

Descriptives

We included 29,855 children (age: 7.07±1.62; height: 127.3 ± 11.5 cm; mass: 27.0 ± 7.6 kg) and 194,360 test scores in the analysis. Among them, 49 % were girls (n=14,749) and 51% (n=15,106) boys. Appendix Table 6 displays descriptive statistics of test scores in their original metric by sex and broken down for two age-groups over the entire measurement period.

Secular trends and COVID-pandemic effects

The RDD provides an analysis of the COVID-pandemic related effects in the context of secular cohort-related trends. Figure 1 displays children´s pre-pandemic and pandemic linear trends for the eight PF test items for 2012–2022 cohorts after adjustment of LMM covariates related to age, sex, body constitution, as well as child- and county-related RES effects. For 2012–2019 cohorts, mean test dates are the middle of the year; for 2020–2022 cohorts, information was available for the month of test. Therefore, we plot by month within years to provide a better visualization of secular trends for the short period of COVID-pandemic cohorts.

The vertical red line marks the RDD critical date (i.e., 2020-12-31) at which the COVID-pandemic change is estimated as the difference between intercepts of linear pre-pandemic and linear pandemic regression lines in the LMM after statistical adjustment for other fixed-effect covariates and RES effects. Red points mark the observed mean z-score for each cohort, mostly occluded by green points, that is predictions estimated from the complete final LMM. Thus, the complete LMM fits the observed means quite well. Black dots mark corresponding means of partial-fitted RDD effects plus model residuals and blue lines for pre-pandemic and pandemic slopes visualize corresponding linear fits of observation-level partial-fitted RDD effects. The corresponding test statistics for cohort/pandemic-related fixed effects of pre-pandemic slope, change in slope between pre-pandemic and pandemic slope (i.e., Δ slope @ crit. date), and intercept differences at the critical date (i.e., Δ Mean @ critical date) are reported in Table 3. Slopes for pandemic regression lines of Figure 1 can be computed by adding estimates of *pre-pandemic slope* and *Δ slope @ critical date*.

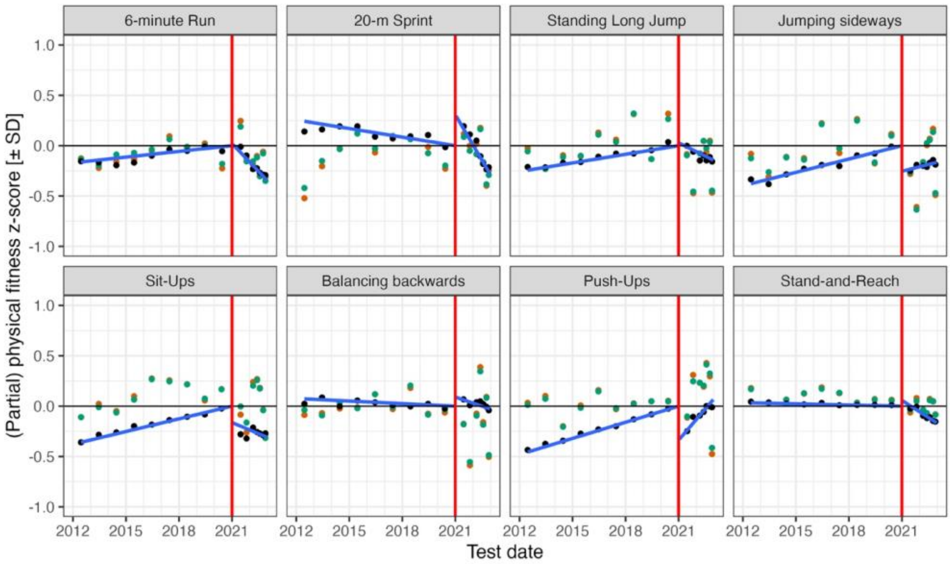

Figure 1. Partial-fitted RDD effects at the assumed critical date of COVID onset (i.e., 2020-12-31; red vertical line) for eight test items. Pre-pandemic and pandemic slopes (blue lines) show corresponding LMM partial-fitted RDD effects. Test statistics for (a) pre-pandemic slopes, (b) differences between pre-pandemic and pandemic slopes, and (c) differences in intercepts at the critical date are provided in Table 3. Red dots = observed means; most of them are occluded by green dots = corresponding means of complete LMM predictions; black dots = corresponding means of partial-fitted RDD effects + model residuals. 20-m-Sprint score is speed (i.e., 20 [m/s])

Table 3. LMM estimates of pandemic-related fixed effects

Test	*Coefficient*	*Estim*	*SE*	*z-statistic*	*p-value*
6-minute Run	*Pre-pandemic slope*	*0.02*	*0.01*	*2.41*	*0.02*
	Δ slope @ crit. date	*-0.20*	*0.05*	*-3.82*	*<0.01*
	Δ Mean @ crit. date	*0.02*	*0.08*	*0.27*	*0.78*
*20-m-Sprint**	*Pre-pandemic slope*	*-0.03*	*0.01*	*-3.73*	*<0.01*
	Δ slope @ crit. date	*-0.27*	*0.05*	*-5.38*	*<0.01*
	Δ Mean @ crit. date	*0.31*	*0.08*	*4.03*	*<0.01*
SLJ	*Pre-pandemic slope*	*0.03*	*0.01*	*4.30*	*<0.01*
	Δ slope @ crit. date	*-0.12*	*0.04*	*-3.08*	*<0.01*
	Δ Mean @ crit. date	*0.03*	*0.06*	*0.48*	*0.63*
JSW	*Pre-pandemic slope*	*0.04*	*0.01*	*6.67*	*<0.01*
	Δ slope @ crit. date	*0.00*	*0.04*	*0.04*	*0.97*
	Δ Mean @ crit. date	*-0.25*	*0.06*	*-4.19*	*0.00*
Sit-Ups	*Pre-pandemic slope*	*0.04*	*0.01*	*5.33*	*<0.01*
	Δ slope @ crit. date	*-0.12*	*0.05*	*-2.16*	*0.03*
	Δ Mean @ crit. date	*-0.16*	*0.08*	*-2.01*	*0.04*

Test	*Coefficient*	*Estim*	*SE*	*z-statistic*	*p-value*
BBW	*Pre-pandemic slope*	*-0.01*	*0.01*	*-1.23*	*0.22*
	Δ slope @ crit. date	*-0.05*	*0.04*	*-1.24*	*0.22*
	Δ Mean @ crit. date	*0.09*	*0.06*	*1.39*	*0.16*
Push-Ups	*Pre-pandemic slope*	*0.05*	*0.01*	*6.80*	*<0.01*
	Δ slope @ crit. date	*0.15*	*0.05*	*2.87*	*<0.01*
	Δ Mean @ crit. date	*-0.34*	*0.08*	*-4.25*	*<0.01*
SaR	*Pre-pandemic slope*	*0.00*	*0.01*	*-0.53*	*0.60*
	Δ slope @ crit. date	*-0.11*	*0.05*	*-2.37*	*0.02*
	Δ Mean @ crit. date	*0.06*	*0.07*	*0.81*	*0.42*

Note. SLJ: Standing Long Jump, JSW: Jumping sideways, BBW: Balancing backwards, SaR: Stand-and-Reach. *20-m-Sprint score is speed (i.e., 20 [m/s]).

For 6-minute-Run a small significant positive pre-pandemic trend was found (b = 0.02, z = 2.41). There was no significant difference between the performances at the critical date (b = 0.02, z = 0.27), but a significant negative change in the cohort trend during the pandemic (b = -0.20, z = -3.82). Thus, there was no evidence for a discontinuity in performance at the critical date, but the COVID-pandemic was associated with a negative change of direction.

20m-Sprint exhibited a small significant negative pre-pandemic linear trend (b = -0.03, z = -3.73) that changed into an even more negative trend for pandemic cohorts (b = -0.27, z = -5.38). In this case, the pandemic intercept at the critical date was estimated as significantly more positive than the pre-pandemic intercept (b = 0.31, z = 4.03) which we interpret as likely due to an artefactual extrapolation of the strong negative pandemic slope back to the critical date.

Standing Long Jump performance increased across pre-pandemic cohorts (b = 0.03, z = 4.30) and this trend again changed significantly negative for pandemic cohorts (b = -0.12, z = -3.08). Intercepts of the two regression lines extrapolated at the critical date did not differ significantly (b = 0.03, z = 0.48).

For Jumping sideways there was a significant positive linear pre-pandemic cohort trend (b = 0.04, z = 6.67). That did not change significantly at the critical date (b =0, z = 0.04). However, performance during COVID-pandemic was significantly lower when estimated at the critical date (b = -0.25, z = -4.19). Thus, statistically, there was a significant discontinuity with a downward shift of a positive trend at the critical date.

Sit-Ups was characterized by a positive linear trend in the pre-pandemic cohorts (b = 0.04, z = 5.33) accompanied by a significant negative change (b = -0.12, z = -2.16) that started at a significantly lower level of performance (b = -0.16, z = -2.01).

For Balancing backwards there was no evidence for cohort-related changes or pandemic effects.

The profile for Push-ups was qualitatively different from the other tasks. Here a positive pre-pandemic slope (b = 0.05, z = 6.80) increased significantly further during pandemic years (b = 0.15, z = 2.87). These positive trends were separated by a large drop in performance at the critical date (b= -0.34, z = -4.25).

The Stand-and-Reach profile represents a prototype of COVID-pandemic effects at the secular trend. A non-significant pre-pandemic slope (b = <0.01, z = -0.53) turned significantly negative across pandemic years (b = -0.11, z = -2.37); the two regression lines did not differ at their intercepts at the critical date (b = 0.06, z = 0.81).

Age, sex, and body constitution effects

Unveiling Covid-pandemic effects shown in Figure 1 required adjustment for covariate effects associated with age, sex, and body constitution estimated in the same LMM. Figure 2 displays observed (i.e., zero-order) age-related developments of performance on test items for boys and girls with higher z-scores always indicating better the performance; partial physical fitness scores showed the same profiles. Corresponding estimates of age and sex effects and their interactions, z-statistics, and p-values, adjusted for each other and pandemic-related effects as well as well as RES effects, are provided in Table 4. Estimates reported in Tables 3 and 4 are based on the same LMM.

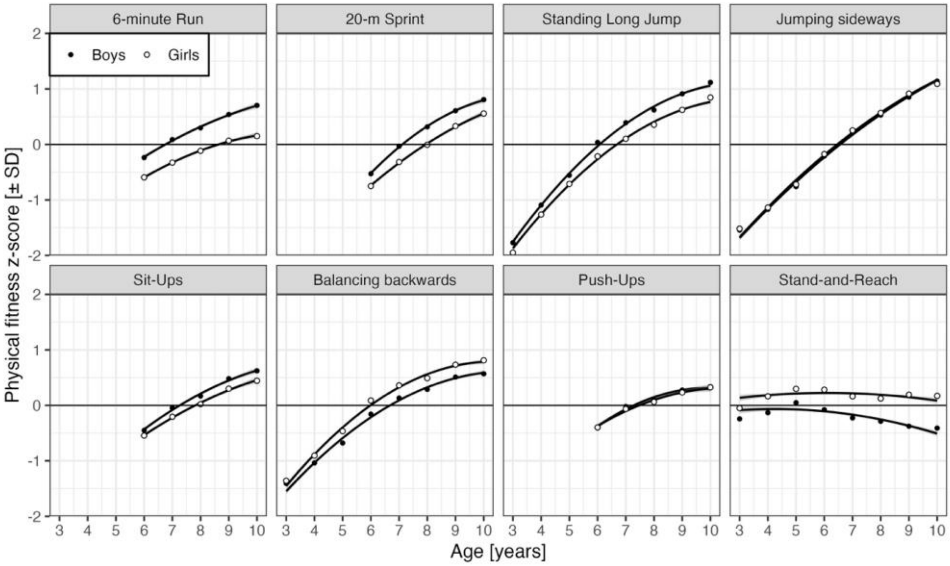

Figure 2. Physical fitness by age, sex, for eight test items. Continuous lines are zero-order quadratic fits to children's z-scores; 95%-confidence bands are too narrow for visibility. Each dot is the mean z-score over the means of age bins representing between 382 and 3,147 children (median: 1,815). 20-m-Sprint score is speed (i.e., 20 [m/s])

Effects of age, sex, and age x sex. There was a significant slowing of the increase of performance with cross-sectional age for all test items (b = -0.01, z = -7.60 to b = -0.04, z = -32.09). Generally, sex differences were in expected directions: Boys significantly outperformed girls in 6-min Run, 20m-Sprint, Standing Long Jump, Sit-Ups, and Push-Ups (b = 0.39, z = 24.19 to b = 0.06, z = 3.90); girls significantly outperformed boys in Jumping sideways, Balancing backwards and Stand-and-Reach (b = -0.03, z = -2.65 to b = -0.38, z = -26.08); except for Jumping sideways, Balancing backwards, and Push-Ups, these sex differences significantly increased with age (|b| = -0.02, |z| = 2.54 to |b| = 0.05, |z| = 7.71; note that performance was stable for girls and decreased for boys in Stand-and-reach).

Table 4. LMM estimates of fixed effects associated with age, sex, and body constitution

Test	*Coefficient*	*Estimate*	*SE*	*z-statistic*	*p-value*
6-minute Run	*sex*	*0.39*	*0.02*	*24.19*	*<0.01*
	age	*0.28*	*0.01*	*27.75*	*<0.01*
	age^2	*-0.05*	*0.00*	*-11.46*	*<0.01*
	sex x age	*0.07*	*0.01*	*6.63*	*<0.01*
	BMI	*0.13*	*0.03*	*3.97*	*<0.01*
	BMI^2	*-0.02*	*0.00*	*-3.66*	*<0.01*

Test	*Coefficient*	*Estimate*	*SE*	*z-statistic*	*p-value*
	sex x BMI	*-0.03*	*0.01*	*-2.84*	*<0.01*
	sex x BMI²	*0.00*	*0.01*	*-0.89*	*0.37*
	height	*0.29*	*0.03*	*11.55*	*<0.01*
	mass	*-0.47*	*0.05*	*-9.62*	*<0.01*
	mass²	*-0.01*	*0.00*	*-2.40*	*0.02*
*20-m Sprint**	*sex*	*0.25*	*0.02*	*16.26*	*<0.01*
	age	*0.44*	*0.01*	*46.27*	*<0.01*
	age²	*-0.07*	*0.00*	*-16.96*	*<0.01*
	sex x age	*0.02*	*0.01*	*2.54*	*0.01*
	BMI	*0.13*	*0.03*	*4.24*	*<0.01*
	BMI²	*-0.02*	*0.00*	*-3.48*	*<0.01*
	sex x BMI	*0.01*	*0.01*	*1.16*	*0.25*
	sex x BMI²	*0.00*	*0.00*	*-0.34*	*0.74*
	height	*0.27*	*0.02*	*11.14*	*<0.01*
	mass	*-0.30*	*0.05*	*-6.64*	*<0.01*
	mass²	*-0.02*	*0.00*	*-6.41*	*<0.01*
Standing-Long- Jump	*sex*	*0.26*	*0.01*	*23.70*	*<0.01*
	age	*0.33*	*0.01*	*56.56*	*<0.01*
	age²	*-0.04*	*0.00*	*-32.09*	*<0.01*
	sex x age	*0.02*	*0.00*	*4.23*	*<0.01*
	BMI	*0.08*	*0.02*	*4.57*	*<0.01*
	BMI²	*-0.02*	*0.00*	*-7.63*	*<0.01*
	sex x BMI	*0.01*	*0.01*	*0.74*	*0.46*
	sex x BMI²	*0.00*	*0.00*	*0.40*	*0.69*
	height	*0.27*	*0.01*	*18.19*	*<0.01*
	mass	*-0.28*	*0.03*	*-10.39*	*<0.01*
	mass²	*-0.01*	*0.00*	*-4.41*	*<0.01*
Jumping sideways	*sex*	*-0.03*	*0.01*	*-2.65*	*0.01*
	age	*0.36*	*0.01*	*61.58*	*<0.01*
	age²	*-0.02*	*0.00*	*-17.89*	*<0.01*
	sex x age	*0.00*	*0.00*	*0.79*	*0.43*
	BMI	*-0.02*	*0.02*	*-1.11*	*0.27*
	BMI²	*-0.01*	*0.00*	*-4.26*	*<0.01*
	sex x BMI	*0.01*	*0.01*	*1.93*	*0.05*
	sex x BMI²	*0.00*	*0.00*	*0.32*	*0.75*
	height	*0.07*	*0.01*	*5.17*	*<0.01*
	mass	*-0.04*	*0.03*	*-1.41*	*0.16*
	mass²	*-0.01*	*0.00*	*-4.07*	*<0.01*
Sit-Ups	*sex*	*0.13*	*0.02*	*8.03*	*<0.01*
	age	*0.32*	*0.01*	*30.86*	*<0.01*
	age²	*-0.05*	*0.00*	*-11.29*	*<0.01*
	sex x age	*0.03*	*0.01*	*2.61*	*<0.01*
	BMI	*0.06*	*0.03*	*1.59*	*0.11*
	BMI²	*-0.02*	*0.01*	*-4.65*	*<0.01*
	sex x BMI	*0.02*	*0.01*	*2.07*	*0.04*

Test	*Coefficient*	*Estimate*	*SE*	*z-statistic*	*p-value*
	sex x BMI^2	*0.01*	*0.01*	*1.99*	*0.05*
	height	*0.18*	*0.03*	*6.86*	*<0.01*
	mass	*-0.20*	*0.05*	*-4.02*	*<0.01*
	mass^2	*-0.01*	*0.00*	*-3.13*	*<0.01*
Balancing Backwards	*sex*	*-0.19*	*0.01*	*-16.44*	*<0.01*
	age	*0.25*	*0.01*	*41.29*	*<0.01*
	age^2	*-0.04*	*0.00*	*-25.88*	*<0.01*
	sex x age	*-0.01*	*0.01*	*-1.40*	*0.16*
	BMI	*-0.03*	*0.02*	*-1.33*	*0.18*
	BMI^2	*-0.02*	*0.00*	*-5.97*	*<0.01*
	sex x BMI	*0.03*	*0.01*	*3.48*	*<0.01*
	sex x BMI^2	*0.01*	*0.00*	*2.54*	*0.01*
	height	*0.04*	*0.02*	*2.58*	*0.01*
	mass	*-0.08*	*0.03*	*-2.58*	*0.01*
	mass^2	*-0.01*	*0.00*	*-3.93*	*<0.01*
Push-Ups	*sex*	*0.06*	*0.02*	*3.90*	*0.01*
	age	*0.26*	*0.01*	*25.90*	*<0.01*
	age^2	*-0.05*	*0.00*	*-11.78*	*<0.01*
	sex x age	*0.00*	*0.01*	*0.43*	*0.67*
	BMI	*0.01*	*0.03*	*0.26*	*0.80*
	BMI^2	*-0.01*	*0.00*	*-2.90*	*<0.01*
	sex x BMI	*0.03*	*0.01*	*2.46*	*0.01*
	sex x BMI^2	*-0.01*	*0.00*	*-1.19*	*0.23*
	height	*0.06*	*0.03*	*2.24*	*0.02*
	mass	*-0.10*	*0.05*	*-2.11*	*0.03*
	mass^2	*0.00*	*0.00*	*-0.98*	*0.33*
Stand-and-Reach	*sex*	*-0.38*	*0.01*	*-26.08*	*<0.01*
	age	*-0.07*	*0.01*	*-10.65*	*<0.01*
	age^2	*-0.01*	*0.00*	*-7.60*	*<0.01*
	sex x age	*-0.05*	*0.01*	*-7.71*	*<0.01*
	BMI	*0.09*	*0.03*	*3.60*	*<0.01*
	BMI^2	*-0.01*	*0.00*	*-1.62*	*0.11*
	sex x BMI	*0.02*	*0.01*	*2.44*	*0.01*
	sex x BMI^2	*0.00*	*0.00*	*0.92*	*0.36*
	height	*0.01*	*0.02*	*0.54*	*0.59*
	mass	*-0.10*	*0.04*	*-2.53*	*0.01*
	mass^2	*0.00*	*0.00*	*-0.42*	*0.67*

*20-m-Sprint score is based on speed (i.e., 20 [m/s]). Covariates of BMI, height, mass are based on age- and sex-adjusted z-scores.

Effects of body constitution. Age- and sex-adjusted BMI-SDS effects on physical fitness are shown in Figure 3. The primary purpose of BMI, mass and lightness covariates was “to unveil” cohort-/COVID-specific trends. As expected, high BMI is associated with strong declines in 6-min Run, 20-m-Sprint, and Standing Long Jump with much smaller declines for low BMI. The declines with low and high BMI are less pronounced and more symmetric for, Sit-Ups, Balancing backwards, Push-Ups, and Stand-and-Reach.

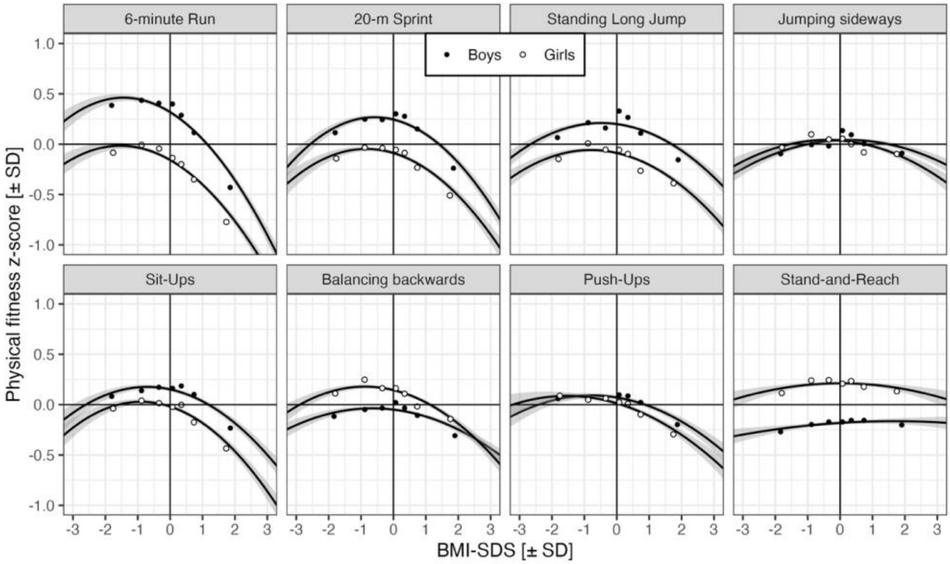

Figure 3. Physical fitness by BMI z-score and sex for eight test items. Continuous lines are zero-order quadratic fits to children's z-scores and 95%-confidence bands. Each dot is the mean z-score over the means of BMI z-scores representing between 1294 and 2228 children (median: 1715). 20-m-Sprint score is based on speed (i.e., 20 [m/s])

The profiles in Figure 3 are the result not only of quadratic BMI-SDS effects (and their interaction with sex) but also of correlated age- and sex-adjusted quadratic mass and linear height effects. Estimates of these effects and their associated standard errors, z-statistics and p-values are reported in Table 4. Except for Stand-and-Reach, BMI-SDS was the primary source of the inverted u-shape profiles, that is negative quadratic trends were significant for the seven other test items (Push-Ups: b = -0.01, z = -2.90 to Standing Long Jump: b = -0.02, z = -7.63). Boys' and girls' profile differed significantly only for Balancing backward (b = 0.01, z = 2.54).

Except for Jumping Sideways and Stand-and-Reach, partial effects of age- and sex-adjusted height and mass covariates were associated with significantly better and worse physical fitness, respectively (height: b = 0.06, z = 2.24 to b = 0.27, z = 18.19; mass: b = -0.10, z = -2.11 to b = -0.28, z = -10.39). Except for Push-Ups, the negative linear effects of mass were moderated by significant negative quadratic trends implying smaller decrements for lower mass (b = -0.01, z = -2.40 to b = -0.02, z = -6.41). Interestingly, for height these effects were opposite to their zero-order correlations, ranging from .00 to -.13. Thus, adjustment for other LMM covariates (including BMI-SDS) unveiled plausible benefits of height and cost of mass for physical fitness.

LMM correlation parameters and zero-order correlations for random factors

RES estimates of variance components (VCs) and correlation parameters (CPs) as well as zero-order correlations for the eight items for both random factors Child and PLZ (see Table 5). For PLZ, in addition, we estimated CPs and zero-order correlations for the COVID effect at the critical date and VCs for pre-pandemic slope, the change in slope from pre-pandemic to pandemic cohorts, linear effect of age, and sex (see Table 5; CPs below, zero-order correlations above diagonals). Primarily, estimation of these model parameters guarded against anti-conservative estimates of fixed effects reported above.

Table 5. LMM variance components and correlation parameters (below diagonal) and zero-order correlations (above diagonal) for random factors Child and PLZ

	SD	***6min***	***JSW***	***20m***	***SLJ***	***SU***	***BBW***	***PU***	***SAR***
Child									
6min	*0.66*		*+0.37*	***+0.46***	***+0.45***	*+0.33*	*+0.25*	*+0.26*	*+0.04*
JSW	*0.42*	***+0.49***		***+0.43***	***+0.67***	*+0.40*	***+0.57***	*+0.42*	*+0.05*
20m	*0.65*	***+0.53***	***+0.56***		***+0.57***	*+0.39*	*+0.29*	*+0.30*	*+0.07*
SLJ	*0.46*	***+0.58***	***+0.78***	***+0.84***		***+0.47***	***+0.53***	*+0.33*	*+0.08*
SU	*0.72*	*+0.34*	***+0.49***	***+0.45***	***+0.58***		*+0.27*	*+0.42*	*+0.09*
BBW	*0.54*	*+0.31*	***+0.58***	*+0.33*	***+0.49***	*+0.27*		*+0.28*	*+0.10*
PU	*0.67*	*+0.31*	***+0.59***	*+0.35*	***+0.45***	***+0.46***	*+0.29*		*+0.12*
SAR	*0.81*	*+0.16*	*+0.24*	*+0.20*	*+0.37*	*+0.16*	*+0.20*	*+0.19*	
PLZ									
6min	*0.57*		*+0.46*	*+0.47*	*+0.44*	*+0.43*	*+0.24*	*+0.35*	*+0.07*
JSW	*0.41*	*+0.33*		*+0.54*	*+0.85*	*+0.65*	*+0.63*	*+0.59*	*+0.15*
20m	*0.46*	*+0.24*	*+0.08*		*+0.58*	*+0.52*	*+0.23*	*+0.40*	*+0.15*

	SD	*6min*	*JSW*	*20m*	*SLJ*	*SU*	*BBW*	*PU*	*SAR*
SLJ	*0.34*	*+0.31*	***+0.50***	*+0.21*		*+0.67*	*+0.63*	*+0.47*	*+0.15*
SU	*0.46*	*+0.26*	*+0.39*	*+0.09*	***+0.45***		*+0.32*	*+0.71*	*+0.18*
BBW	*0.54*	*+0.17*	*+0.24*	*+0.02*	*+0.31*	*+0.23*		*+0.35*	*+0.18*
PU	*0.63*	*+0.19*	*+0.43*	*+0.03*	*+0.20*	***+0.60***	*+0.20*		*+0.11*
SAR	*0.37*	*+0.13*	*+0.23*	*+0.32*	*+0.33*	*+0.32*	*+0.22*	*+0.12*	
CVD	*0.32*	*-0.26*	***-0.50***	*-0.28*	***-0.69***	*-0.22*	*-0.14*	*-0.04*	*-0.42*
PS	*0.04*								
CVD x PS	*0.10*								
Age	*0.06*								
Sex	*0.05*								

Bold: r >=.45 (>20% shared variance). Zero-order correlations above diagonal are based on pairwise-complete test data. SD: Square root of variance component (VC); 6min: 6-minute Run; JSW: Jumping sideways; 20m: 20 m sprint; SLJ: Standing Long Jump; SU: Sit-Ups; BBW: Balancing backwards; PU: Push-Ups; SaR: Stand and Reach; CVD: Covid-effect at critical date; PS: pre-pandemic linear slope; Age: linear effect of age; Sex: effect of sex. Residual variance: 0.48.

For Child CPs there is a well-defined latent construct of physical fitness comprising 6-min Run, Jumping sideways, 20-m Sprint, Standing Long Jump, and Sit-Ups with correlation ranging with one exception between .45 and .84. Moreover, Jumping sideways and Standing Long Jump also correlated in this range with Balancing backwards and Push-Ups; Stand-and-Reach did not correlate with the other items. Corresponding zero-order correlations exhibited a similar pattern with smaller correlations ranging from .33 to .67.

A similar pattern was not observed for county (PLZ) CPs, but there were too large negative correlations between the COVID effect and Jumping sideways (r=-.50) and Standing Long Jump (r=-.69). Thus, better performance in these items correlated with larger (i.e., more negative) COVID effects at the critical date.

Discussion

Monitoring and surveillance of PF especially in children is crucial given the importance and relationship with numerous health benefits. It gets even morgen essential as COVID pandemic influenced life and conditions of physical activities (Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020). Even though, there are already several studies on trends in PF over recent years, the lack of a standardised and long-term monitoring with large data sets is still obvious in PF research (Lang et al., 2023). Therefore, we conducted an analysis of secular trend in PF since 2012 in the federal state of Baden-Württemberg, Germany. Taking advantage of data pooling, we could also implement the COVID pandemic as a quasi-experiment and investigate its potential effects.

First, we examined secular trends in PF of children over a 10-year period and therefore used data of 29,855 children in 1,312 events from eleven cohorts. Children were tested with a consistent test profile over the entire time, resulting in 194,360 observations in eight PF test items. This enables a comprehensive and global evidence of secular trends in PF of the tested children. To consider the particular influencing factor of COVID pandemic, we implemented an RDD within the used linear mixed model. Consequently, we generated information of secular trends in PF for the recent years, and also tested if the COVID pandemic is accountable for possible apparent changes.

Pre-Pandemic Trends in Physical Fitness

For the pre-pandemic cohorts, we found significant, but relatively small trends in six out of eight test items over the years of assessment. This trends in performance of PF goes in line with latest research findings, reporting a weakening of the occurred downshift at the end of the 20th century (Eberhardt et al., 2020; Fühner et al., 2021).

For endurance, assessed by the 6-minute Run we found a small linear increase before COVID-pandemic since 2012. Knowing, that the trend is particularly slight, this finding is fundamentally the same as Tomkinson et al. (Tomkinson et al., 2019) reported a diminishing of the substantial decline with negligible changes since 2000 in cardiorespiratory fitness. Radulović et al. (2022) also found a plateauing performance in the last decade in Slovenian children. The test items assessing strength of different parts of the body, were characterized by a slight positive linear trend for pre-pandemic cohorts. Equally, Fühner et al. (2021) reported a recent increasing trend in relative muscle strength until 2015, but also with the magnitude of the trend being small. For Germany, the representative MoMo-study reported a consistent level for Standing Long Jump and Push-Ups in all examined age groups including children aged 4 to 10 years and supports our findings on a national level (Hanssen-Doose et al., 2021).

For Jumping sideways, as specific task for coordination under time-pressure, which is a combination of the abilities coordination and speed, a small positive pre-pandemic trend was found. Interestingly, there was no evidence for a pre-pandemic trend in Balancing Backwards and Sit-and-Reach. Balancing Backwards and Sit-and-Reach involve minimal, if any, energy-driven effort, as they primarily relate to information-based abilities like coordination and flexibility, which function as passive systems of energy transfer (Bös & Mechling, 1983).

It appears that the recent efforts to promote physical activity and physical fitness may have started to reverse the previous downward trend, resulting in a slight positive improvement. However, these interventions have primarily focused on enhancing conditional abilities, potentially overlooking the importance of developing coordinative aspects of physical fitness. While this could explain the observed trends, we cannot definitively say that this is the sole reason, as other factors may also play a role. The impact of these interventions on coordination remains uncertain and requires further investigation. To promote physical fitness as a multidimensional construct, interventions should develop the wider base of physical fitness in a comprehensive and holistic way. The expected increasing development over age for the test items is consistent with recent literature (Niessner, Utesch, et al., 2020). As previously reported in theoretical concepts, the increase of performance in PF is the biggest for children aged 3-to-10 years (Willimczik & Conzelmann, 1999). Especially, this age span is extraordinary important for motor development. Here, goal-oriented and situation specific movements are built which the base of acquisition of a variance of motor actions and skills. Compared to earlier stages of motor development, movements are characterized by more economy and variability, so that children know better how to use their skills (Bös & Ulmer, 2003). This underscores the importance of promoting physical fitness early in life through a comprehensive approach that addresses all dimensions. It not only supports general motor development, but also lays the foundation for a wide range of motor skills that either encourage or discourage an individual to be physically active and maintain future PF (Fraser et al., 2021; Utesch, Dreiskämper, Strauss, et al., 2018).

COVID-Pandemic Trends in Physical Fitness

Regarding the findings that the long-term downward trend in physical fitness has recently stabilized, the occurrence of the COVID-19 pandemic was particularly relevant for children's routines in physical activity and levels of PF. Setting the critical date for possible COVID-effects and pandemic-trends, the results demonstrated a significant negative change across pandemic years. Even if there was no significant difference between the two trends in the intercept at the critical date, our finding suggests a negative influence of COVID-pandemic on level of PF or even interrupt the consistency. Equally, Teich et al. (2023) reported lower performance in cohorts 2020-2022 compared to pre-pandemic cohorts for children and they estimated developmental delays from approximately 5 months in endurance for these children.

For endurance and speed, the negative trend for pandemic cohorts was particularly evident. From a sports science perspective, endurance is an ability that demands long-term, systematic, and high-intensity training to achieve and sustain a certain level of performance

(Basterfield et al., 2022; Drenowatz et al., 2023). Additionally, there is much space needed to exercise endurance and the determining cardiorespiratory system. Therefore, they were particularly vulnerable for restrictions and limitations affecting physical activity routines like closure of sport clubs or schools. The persistent negative trend even after the restrictions shows also that children have not yet been able to reverse the negative COVID-effects at all. It is necessary to implement targeting actions to diminish the developmental loss for children. As already said, this is even more crucial for children within an age, where foundations for a lifelong active lifestyle is laid.

For speed, in addition to the large negative change within the trend, there was a discontinuous increment at the critical date which was surprising. Most likely, this is a methodological issue due to the setting of the critical date and not an actual objective estimate. We set the onset of the critical date at 31-12-2020 for various reasons. Even if the first restrictions and closures occur earlier in Germany, they do not affect PF immediately as PF is a relatively stable construct (Schilling et al., 2021; Utesch et al., 2019). In the cohort of 2020, less children were tested compared to previous cohorts and when, it was mainly in the second half of the year. Hence, we had no statistical power for an earlier set of critical date. For example, Teich et al. (2023) set the critical date with the begin of the school year and all children were tested from September to November. Nevertheless, it is difficult to determine an exact day, because we do not know when effects of the COVID pandemic on PF occur precisely. Possibly, they also differ between the dimensions and it cannot be excluded that age and sex are influenced factors, too. Overall, our findings did not change substantially, but show the same qualitative pattern, when setting the critical date earlier or later. Therefore, we state that the estimated pandemic effects are valid.

The small positive pre-pandemic trend in test items assessing strength of lower limbs and the trunk changed into negative at the critical date and indicated a change of direction in performance due to COVID-pandemic and related restrictions. In accordance, within one full year of restrictions in France, children namely suffer a loss of performances in Standing Long Jump, but as in our analyses, effects were weak (Chambonnière et al., 2021). Indeed, the development of PF is a long-term and unique process with multidirectional schemes and plasticity influenced by additional factors. It seems therefore logical, that changes and adaptions occur not immediately and short-term in a full extend (Stojan et al., 2023). When considering trends, whether before, during or after COVID-pandemic, it is critical to follow up the monitoring regularly for a comprehensive and clear evidence of effects. Nevertheless, the direct assessment even of weak changes and slight tendencies could already provide evidence for immediate interventions and actions and help to diminish the impact. Stojan et al. (2023) report differentiated results of COVID-pandemic effects for various test items with the pandemic effect being most pronounced in Push-Ups. This variety in results should be considered additionally, when assessing further trends and effects in PF and emphasize the importance of a wide-ranged monitoring. In our sample, the performance from Push-Ups for upper limbs strength showed qualitatively different profiles for COVID-pandemic cohorts. There was a significant discontinuous decrement at the critical date, but the positive direction of trend did not change afterwards and was still significant. The findings indicate, that COVID-pandemic had an influence, causing the level of performance to decline briefly. However, and this also helps to explain the small changes in Standing Long Jump and Sit-Ups, the children were obviously able to compensate the drop quite quickly. Teich et al. (2023) reported also a returning increase of performance from 2021 to 2022 after initial decline. Strength appears to be a more resilient dimension in relation to the negative effects of the COVID-19 pandemic. The limited opportunities of exercising through cancelled organized forms in sports clubs or physical education lessons primarily affected other dimensions, rather than strength. During COVID-pandemic the forms of being physically active changed and non-organized physical activity time increased due to the restrictions. In more detail, the time spent for habitual physical activity and playing outside was more than before the COVID-pandemic (Schmidt, Burchartz, Kolb, Niessner, Oriwol, Hanssen-Doose, et al., 2021b). It is well known that even the activities of daily life are not just minimal demands and strains on children's performance, but have a level of intensity that requires and promotes strength (Baur et al., 2009). Additionally, when doing exercises such as workouts at home, there is smaller space needed for tasks and skills which reinforce in particular strength.

For specific test items of coordination, we found no evidence for changes of pandemic trends compared to pre-pandemic. The assessment of coordination reveals some methodological issues and they are obvious in recent studies of trends. As an important dimension of the health-oriented PF concept, it is important to measure coordination, but is challenging, because of its complex and multidimensional composition of muscular, sensorial and cognitive components. Regarding COVID, coordinative tasks appear to be less affected by negative influences compared to conditional abilities, as the multifaceted nature of coordination allows for better mitigation through information-oriented aspects, such as cognitive processes (Baur et al., 2009).

BMI and Physical Fitness

There are also specific sex-related aspects concerning coordination as girls outperform boys in this and in flexibility. In contrast, there were benefits for boys and growth rates were higher over the included age span for the other dimensions of endurance, speed and strength. In addition, for coordinative ability another common pattern is obvious. As Figure 3 illustrates the quadratic effects of BMI-SDS and thus inverted u-shaped plots indicate different impact of BMI in the specific test items. Especially 6-minute Run, 20-m Sprint and Standing Long Jump are strongly influenced by BMI. Previous evidence determined the relationship of overweight and obesity with PF already in different schemes (Chen et al., 2022; Cochrane et al., 2015; Dong et al., 2019; Kwieciński et al., 2018; Rauner et al., 2013). Cochrane et al. (2015) indicated a significantly higher probability of overweight for children with low PF, while others stated overweight as potential covariate of PF (Chen et al., 2022). The obvious quadratic trends of BMI in PF and thus inverted u-shaped plots indicate an optimum level of BMI with beneficial influence on level of PF. With our findings, we can confirm, higher BMI results in lower PF especially in conditional abilities as endurance, strength, and speed (T. S. Olds et al., 2007; Tomkinson et al., 2019). In particular, these are the test items where mass has to be moved fast and for a long time. Considering the emergent coherency between the different variables PF, obesity and overweight, and also physical activity and health, it is crucial to break through the cycle (Lima et al., 2021; Olds et al., 2011). In line with this, we showed that higher mass is negatively associated with PF and also results in larger decrements in PF, whereas there is a positive association of height with PF. However, positive effect of height is only obvious in partial effects statistics. This points out the relevance of considering these variables separately as they have a significant influence, but also adjust them within the statistical model to regard them comprehensively.

Methodological Considerations

For speed, in addition to the large negative change within the trend, there was a surprising discontinuous increment at the critical date. This is likely a methodological issue due to the setting of the critical date, rather than an actual objective estimate. We set the onset of the critical date at 31-12-2020 for various reasons. Although the first restrictions and closures occurred earlier in Germany, they did not immediately affect PF, as PF is a relatively stable construct (Schilling et al., 2021; Utesch et al., 2019). In the 2020 cohort, fewer children were tested compared to previous cohorts, and testing mainly occurred in the second half of the year. Hence, we lacked statistical power for an earlier critical date. Overall, our findings did not change substantially but showed the same qualitative pattern when setting the critical date earlier or later. Therefore, we state that the estimated pandemic effects are valid.

For our analyses, we had benefitted of sufficient large data and comprehensive sample in the federal state Baden-Württemberg. It points out the particular need of standardized and continuous assessment of PF in children. The standardized measurement profile enables consistent annual measurement. While some studies only compared a few individual measurement points, we have had regular data since 2012 within the same uniform sample. This ensures a high degree of comparability over the years and certain homogeneity, as required in recent research (Lang et al., 2023; Lopes et al., 2020). For reporting trends in children´s PF between different populations and over time, an international collaboration and consensus in assessment tools is needed to strengthen the impact of evidence on public health actions. The implementation of a standardized test protocol with common scalable values and metrics help to identify patterns and regions, i.e. with regard to COVID pandemic changes. However, the data reported and analysed are still short-term effects of the COVID-19 pandemic. Whether this is just a short-term dip that will recover over the next few years, or a long-term bend, needs to be investigated further.

Our analyses based on a big data set was possible through data pooling. With the repository MO|RE data (www.motor-research-data.de), we pooled data from existing data sets into a large sample which allows us to analyses the impact of the pandemic not only in a limited small group. A collaborative collection and centered generation of data from existing studies in the repository can derive global trends cross-nationally. MO|RE data is discipline-specific and addresses the specific demands and requirements of data in physical fitness (Klemm et al., 2024). It is practical to report and consider the different dimensions and test items separately, because of their specificity of results. Most of the studies only examine particular aspects of physical fitness, but it is even more meaningful if a sample has been analysed with regard to all components of fitness to obtain a more universal profile.

Limitations

However, our study is not without limitation. It focuses mainly on short-term analyses, which raises the question of how the observed effects play out in the long-term. Moreover, there is a lack of additional information, such as socioeconomic status (SES) and the children's general physical activity, which could provide important contextual information. Methodological limitations affect the generalizability of results. Although the data analysed is large and consistent, it does not fulfil the requirement of national representativeness as only an ad-hoc sample from the federal state of Baden-Wuerttemberg is included. Despite these limitations, the study provides valuable insights into the impact of the COVID-19 pandemic on children's PF and highlights the need for further long-term studies to better understand the lasting effects.

Conclusion

Monitoring of PF in children at the population level is crucial. Continuous and long-term analyses of trends are essential, particularly in light of the decline in PF caused by the pandemic. It enables early identification of negative trends, allowing targeted interventions to be planned and implemented. Schools and communities must introduce systematic programs to promote physical activity and counteract the pandemic-related PF losses. Especially, as childhood is the phase of development where the foundation is laid for a healthy and active lifestyle. Among this “critical motor learning age” even small changes can have a significant impact on the long-term development of PF. The evidence serves as the basis for policy decisions and health strategies in Baden-Wuerttemberg, Germany. It enables evidence-based and data-driven implementation of programs and allocate resources more efficiently to improve children's PF and well-being and in particular mitigate negative effects of the pandemic. Finally, monitoring raises the awareness of public and society. Parents, teachers, communities, and relevant actors are informed and can contribute actively to promote a healthy lifestyle. In the long-term, this will lead to a more active and healthier society that is prepared for future challenges.

CHAPTER 6

The Fitness Barometer: A Best Practice Example for Monitoring Physical Fitness

As noted in the current state of research, monitoring physical fitness in children is critical because of its health-related association and its impact on an active lifestyle. Systematic monitoring of levels, trends, and changes in physical fitness provides the opportunity to derive evidence-based strategies and interventions(Eberhardt et al., 2020). o overcome common problems of large samples and long-term continuous implementation, MO|RE data offer the possibility of pooling data from different samples(Eberhardt, Keller, et al., submitted). In addition, it requires a standardized assessment of physical fitness and a large effort in data collection (Eberhardt et al., 2020; Lang et al., 2023). In cooperation with the Institute of Sports and Sports Science and the Kinderturnstiftung Baden-Württemberg, a standardized project called "The Fitness Barometer" was developed in the German state of Baden-Württemberg to benefit from data pooling for monitoring physical fitness. It therefore serves as a best practice example (Eberhardt et al., 2021).

Due to limited resources and difficulties in generating adequate sample sizes, data collection was conducted by practitioners directly in their specific settings, i.e. kindergartens, schools and sports clubs. The GMT, described above, serves as an effective and practical assessment tool for physical fitness and has been further developed into the Kindeturntest Plus (KITT+) to make it even easier to administer to the target group. (Bös et al., 2020a, 2020b, 2023). The multipliers measure the level of performance in the different dimensions of physical fitness and enter the data into an evaluation software. This anonymized raw data forms the basis for the annual analysis and publication of the Fitness Barometer. Using a data-driven approach, we explored the data set to identify patterns and trends. Two editions of the Fitness Barometer have been published as scientific papers (Eberhardt et al., 2021; Kloe, Niessner, et al., 2020). The annual publication of the Fitness Barometer also includes a variety of materials such as press releases, presentations to audiences, and fact sheets to reach multiple audiences, stakeholders, and policymakers. Overall, the samples comprise data of children aged 3-to-10 years and measurements from 2012 onwards. The sample in the first publication of the Fitness Barometer in 2019 included 18.977 children [mean ± SD: age = 6,73 ± 1,71; weight: 25,9 ± 7,4 kg; height = 124,9 ± 12,0 cm] and was the foundation for the further extending (Kloe, Niessner, et al., 2020). With regard to practicability and simple understanding of results, the level of physical fitness and BMI were classified into age- and sex-specific reference percentiles compared to a nationwide representative sample (Albrecht et al., 2018; Kloe, Oriwol, et al., 2020; Kromeyer-Hauschild et al., 2001). To state an overall and general level of physical fitness, sum scores were calculated out of the separate test items. Statistical analyses were carried out with IBM SPSS Statistics. Depending on the research question, descriptive statistics, t-tests and single analysis of variance were examined (Eberhardt et al., 2021).

However, as mentioned by van Bon-Martens et al. (2019), population health reporting aims to create messages of knowledge and awareness in various ways that fit the needs of the target group, but are not determined by statistically high-quality analyses (van Bon-Martens et al., 2019). In addition, this chapter aims to provide an insight into the Fitness Barometer and how monitoring can be implemented and look like in practice to provide value for evidence-based public health. In the DIKW model, it can be categorized in the knowledge level and therefore simply report the results of the data, but also provide explanations and important statements for translation into practice (van Bon-Martens et al., 2019; Verschuuren & Van Oers, 2020). For this reason, the annual publications will not be further processed with a detailed description of scientific methods, values and results. Instead, the individual content-related and graphical processing is presented in more detail to provide an overview of the Fitness Barometer as a best practice example for monitoring physical fitness with pooled data collected from practitioners. The barometer shows the number of children included for the year and indicates the level of physical fitness with the arrow, using different colors for easy evaluation (Figure 1).

Figure 1. The Fitness Barometer illustration for the individual years

There are two main questions of the Fitness Barometer that are answered each year with the newly available data:

- How many children have been tested in Baden-Württemberg, and when and where have they been tested?
- How fit are the children in Baden-Württemberg?

The answers to these descriptive questions are presented comprehensively and in comparison, to the total population of Baden-Württemberg. First, the individual number of children tested within the different years and the percentage compared to the total population of children aged 3-10 in Baden-Württemberg are reported. Then the measurement period and the different communities where the measurements were made are shown. The test sites are marked on the map of Baden-Württemberg. This makes it possible to emphasize the widespread distribution of the assessments, but also to highlight regions that are poorly represented. (Figure 2). In order to answer the main question of the current level of physical fitness (Figure 3), the overall percentile value of the sample is presented and related to the current state of research and previous results of the nationwide sample (Albrecht et al., 2018).

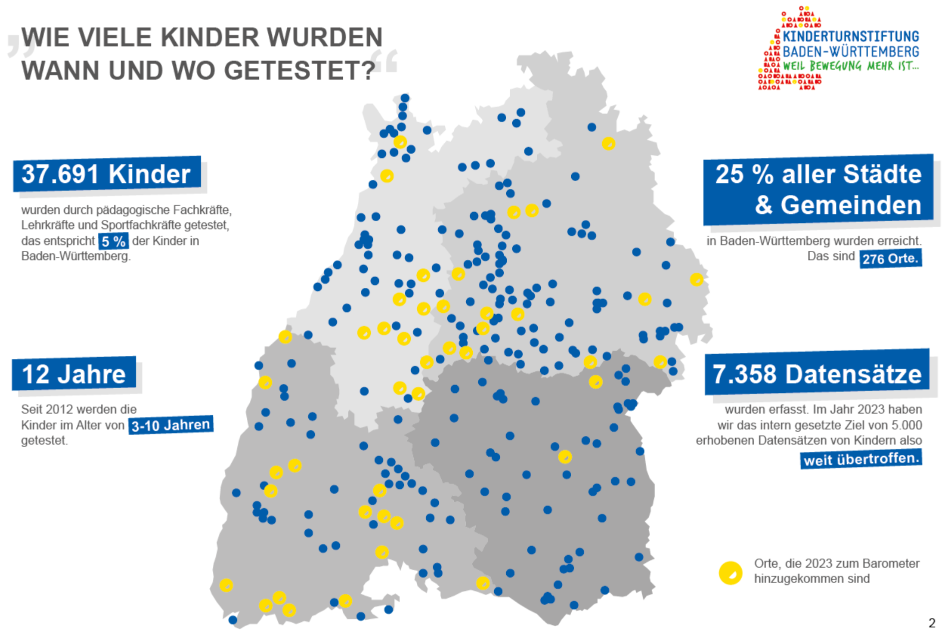

Figure 2. Presentation of descriptive values of the Fitness Barometer and distribution of assessments within Baden-Württemberg (Kinderturnstiftung Baden-Württemberg, 2024, p. 2)

Figure 3. Physical fitness of children within the Fitness Barometer (Kinderturnstiftung Baden-Württemberg, 2024, p. 4)

In addition to the main questions, a third specific focus is included in the Fitness Barometer each year. It provides additional information on current relevant topics or other variables that influence physical fitness. For example, the current level of BMI and its relationship to the level of physical fitness was examined in different age groups. For ease of understanding and practicality, it has been categorized within reference values and allows for percentages of how many of the children included are normal weight, overweight, and obese. Based on the known positive effects of physical activity and physical fitness in overweight children, practical implications and messages for practitioners were derived from the findings. These include examples of games and exercises to help overweight children feel confident about their physical fitness (Figure 4). In addition, a call to action based on the findings of the Fitness Barometer is addressed to relevant policy and decision makers (Figure 5).

Figure 4. Practical implications derived from findings of the Fitness Barometer (own unpublished presentation)

„ES BESTEHT HANDLUNGSBEDARF!
WAS IST ZU TUN?“

KINDERTURNSTIFTUNG BADEN-WÜRTTEMBERG
WEIL BEWEGUNG MEHR IST...

Gemeinsam für gesunde Kinder durch Bewegung!

Bewegung ist ein wichtiger Motor für die körperliche, psychische, sozial-emotionale und kognitive Entwicklung von Kindern. Deshalb braucht ein gesundes Aufwachsen von Kindern auch eine qualifizierte Bewegungsförderung in Kita, Grundschule und Verein. Das gesellschaftliche Problem, der Bewegungsmangel von Kindern, hat sich durch die Corona-Pandemie verstärkt. Zudem leiden die Kinder unter den Einschränkungen doppelt, denn Physis und Psyche hängen ganz eng zusammen. **Gerade jetzt müssen wir als Netzwerk unsere Kräfte bündeln und Kinder in ihrer Lebenswelt (wieder) abholen, sie für Bewegungsangebote gewinnen, die ihnen Freude an Bewegung, Spiel und Sport mit Gleichaltrigen vermitteln!**

Und weiter: Um eine Benachteiligung von Kindern durch bestimmte soziale Faktoren zu vermeiden, gilt es durch eine landesweite Strategie, Bewegung, Spiel und Sport in Kitas, Schulen und Vereinen entsprechend zu stärken und bewegungsfördernde Rahmenbedingungen für Kinder zu schaffen - wie etwa Grünflächen, um Kindern neben dem organisierten Bewegungsangeboten auch freie Bewegungsmöglichkeiten zu bieten.

„Anhand eines beispielhaften Tagesablaufes eines Grundschulkindes wird deutlich: Kinderwelt ist eine Bewegungswelt! Wir haben schon von vielen Forscherteams und Fachkräften in den Medien gehört: Sport ist nicht die Ursache, sondern die Lösung. Aktuell leiden Psyche und Physis unserer Kinder. Deshalb hoffen wir sehr, dass die Politik nicht mehr vorwiegend die Infektionsketten betrachtet, sondern auch diese Auswirkungen im Blick behält und fordern im Sinne einer gesunden Entwicklung unserer Kinder schrittweise Öffnungen der Turn- und Sportvereine.“

Susanne Weimann, geschäftsführender Vorstand der Kinderturnstiftung Baden-Württemberg

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Figure 5. Appeal to action derived from the findings of the Fitness Barometer (Kinderturnstiftung Baden-Württemberg, 2021, p. 10)

The Fitness Barometer is a best practice example of how monitoring of physical fitness can be implemented in practice and provide benefits for practice and research. It shows which relevant key questions can be addressed and how this leads to practical consequences and implications (Eberhardt et al., 2021). Involving practitioners in the data collection process ensures a field-based assessment in different settings of children's daily lives. As needed, a multidisciplinary approach with collaboration between many partners and the inclusion of specific expertise and perspectives is fulfilled and helps to raise awareness and acceptance of the findings (Lopes et al., 2020). The pooling of data allows for monitoring based on a large sample with broad distribution. Therefore, the GMT and KITT+ with their standardized test items, but economical and feasible implementation, combine the differentiated requirements and demands of research and practice (Bös et al., 2023, 2020b, 2020a; Lopes et al., 2020). This chapter aimed to demonstrate the Fitness Barometer as best practice example of monitoring physical fitness and in particular the effort put into the annual publication for the public despite the scientific publications. Nevertheless, scientific analysis, interpretation, and publication is needed to monitor physical fitness. Referring to the information pyramid, without conquering the level of information through comprehensive analyses and interpretation of findings with the help of current state of research, it is unfeasible to reach the next level of knowledge and act reasonable (Verschuuren & Van Oers, 2019).

CHAPTER 7

General Discussion

The aim of this dissertation was to investigate the current situation, trends and changes in children´s physical fitness using a test-diagnostic practice based on the ability-oriented approach and data-driven analyses. The findings constitute an evidence-based monitoring and will be used to derive further strategies and actions for physical fitness promotion regarding the potential for an active and healthy lifestyle.

The structure of the dissertation and the included papers are followed in a classical structure of a scientific article: As a first paper, we conducted a review summarizing the current state of research on secular trends in children´s physical fitness (Eberhardt et al., 2020). In order to overcome the issues of monitoring identified in the review, we published a methodological discussion of the possibilities offered by MO|RE data for physical fitness research (Eberhardt, Keller, et al., submitted). The third and fourth papers are comprehensive results of this specific procedure, examining the current situation, trends and changes in physical fitness. As the occurrence of the COVID-19 pandemic was an influencing factor within the purpose, it was considered as well (Eberhardt, Bös, et al., submitted; Eberhardt et al., 2022). In addition to the scientific papers, an implemented best practice example of monitoring physical fitness is presented for two reasons: It illustrates the main purpose of the preceding papers, how monitoring of physical fitness looks like in practice, and it became a fundamental result of this dissertation (Eberhardt et al., 2021; Kinderturnstiftung Baden-Württemberg, 2019, 2020, 2021, 2022, 2023, 2024; Kloe, Niessner, et al., 2020).

We were able to identify the dynamics of physical fitness across all dimensions and within different specific samples through different analyses. In addition, we were able to identify and realize specific challenges and requirements within the monitoring of physical fitness in children. Based on this, the central results of this work are:

- There is an overall declining trend in the physical fitness of children and adolescents internationally, but findings vary for the specific dimensions of physical fitness and other variables. With regard to former generations, children are less physical fit. The trends are characterized by only slight decreases or constant levels of physical fitness. For recent years, the declining trend weakened and therefore we state a “stagnation on a low level”.
- The occurrence of the COVID-19 pandemic was an influencing factor and provoked changes in physical fitness. In particular, pandemic trends were more negative than pre-pandemic trends. Previously adequate levels of physical fitness increase resilience to such a

sudden onset. Specific initiatives and commitments to promote physical fitness are important to maintain it in challenging circumstances.

- There is an essential need for standardized assessment of physical fitness with consistent measurement batteries, regular and long-term measurement points and a large sample sizes to be able to monitor physical fitness in children. The specific dimensions of physical fitness should be specifically analysed to comprehensively address the multidimensional construct of physical fitness. To overcome these challenges, data pooling and a data-driven approach are suitable, as they allow different datasets to be brought together and patterns of physical fitness to be identified in a more experimental way.
- It is not enough to monitor physical fitness from a scientific perspective alone. Rather, it is essential to prepare the results in a way that they can be understood by the general public and, in particular, by decision-makers, focussing on the relevant information. Only an appropriate dissemination of evidence-based public health monitoring will lead to a feasible and beneficial understanding of the findings.

Overall, in our work analysed numerous international large-scale epidemiological studies and a found a decline in children´s physical fitness (Eberhardt et al., 2020). In line with our work, further reviews have been conducted with the same objectives and mainly the same included studies (Fühner et al., 2021; Masanovic et al., 2020). There are varying findings for the specific dimensions. Since the end of the 20th century, there has been an international declining trend in endurance, but it has not been linear and steady. Rather, there has been a visualizing cubic trend with an initial increase, followed by a decline until 2010 and a recent stabilization or even improvement (Fühner et al., 2021). At a national level, and in continuation, we found evidence of a slight increase in children´s level of endurance since 2012 (Eberhardt, Bös, et al., submitted). Tomkinson et al. (2019) updated the results in cardiorespiratory fitness, calculated with peak oxygen uptake (VO_{2peak}) and operationalized with 20-m shuttle run. They found the same patterns and, in addition, a larger decline for boys (Tomkinson et al., 2019).

Already for endurance, it is obvious that there exist various test items and methodological approaches to assess and analyse trends. The situation is even more complex with regard to strength, as different terms are used to aggregate the test items and the findings vary depending on the part of the body (Eberhardt et al., 2020). Following Bös et al (1987) and summarizing strength in total with test items of lower-, upper body and trunk, we observed an international declining trend with reported data until 2014. However, our analyses within Germany since 2012 revealed slight increases for these test items and are particularly supported by the nationally representative cohorts of the MoMo study, which reported consistent levels over time (Eberhardt, Bös, et al., submitted; Hanssen-Doose et al., 2021). In addition, Fühner et al. (2021) also reported a general trend toward small increases in muscle strength, e.g. sit-ups and push-ups, but a small negative trend in muscle power, e.g. standing long jump. The overall picture is probably even more complex, as the results for standing long jump differed, depending on the time period examined (Eberhardt, Bös, et al., submitted; Tomkinson et al., 2021).

For the entire period of the last 50 years, there has been an improvement per decade, but the magnitude of 1.73 cm is negligible. Since the beginning of the century, performance in the standing long jump has declined when international data are summarized (Tomkinson et al., 2021). The reported trends differ depending on whether they are reported nationally or internationally. The effect sizes within all analyses are small regardless of the direction of the trend reported, and differences may well be due to the methodological approach, as pooling large amounts of data and analysing summary statistics rather than raw data often veil some effects. This illustrates the importance of both specific and comparative considerations when analysing trends in physical fitness.

Speed is usually assessed with linear sprints of varying lengths. Due to inconsistent results, no trend direction could be determined within the studies included in our review, but a small negative trend was observed nationally since 2012(Eberhardt, Bös, et al., submitted; Eberhardt et al., 2020). Other reviews have also reported global ups and downs with a positive cubic trend and flat curves (Fühner et al., 2021; Tomkinson, 2007).

While endurance, strength, and to some extent speed are well established and studied dimensions of physical fitness, there are fewer studies investigating coordination and flexibility internationally. However, they are essential to the ability-oriented approach in order to assess the multi-complex construct of physical fitness in a comprehensible way (Bös & Mechling, 1983). This approach is even widespread in Germany, which is why German studies in particular have reported trends in coordination. Even these measured different aspects within coordination. Coordination under time-pressure showed a slight positive trend. For the more static coordination under precision demands there was no evidence of a trend since 2012, indicating a stagnation, which is consistent with findings in another static test item since 2009 (Eberhardt, Bös, et al., submitted; Hanssen-Doose et al., 2021). In addition, comparisons with an older sample showed a decline for former decades as poorer levels were evident in recent years (Roth et al., 2010).

Flexibility as a dimension of passive systems of energy transfer is also only considered to a limited extent in studies. There was an overall decreasing trend within flexibility internationally, but the level was stable for the last years within our national sample (Eberhardt, Bös, et al., submitted; Eberhardt et al., 2020). Colley et al. (2019) also reported that flexibility was stable over a ten-year time period since 2007. However, they compared these findings to data from 1981 and found significantly lower observed scores for the most recent measurement points of flexibility (Tremblay et al., 2010).

Overall, the separate results of individual studies for the specific dimensions make the "stagnation on a low level" evident. The declining trends in physical fitness are particularly evident for measurement points before the beginning of the 21st century and over long time periods. For the last decades since 2000, the trends are stagnant and are less obvious, but the findings are not as optimistic as they seem. In fact, earlier generations of children were 10 % fitter and when considering the stagnation, it is important to keep in mind the absolute level of trends and changes. Even small positive trends can only reduce or stop the differences between previous and current levels of physical fitness in children.

We have also analysed the data separately by sex, and other studies have done so as well. However, although there were some sex-specific differences in trends within the samples, there is no evidence that this is a determining variable and that the trends are explicitly sex-specific. Rather, these are indirect effects that influence other more determinant factors that affect trends in physical fitness. Physical fitness is affected by multiple factors that are behavioural, social, psychological and environmental components. There is a strong reciprocal relationship between physical activity and physical fitness and evidence of a significant positive association (Bouchard et al., 2012; Larsen et al., 2015; T. S. Olds et al., 2007; Stodden et al., 2008). In addition, sedentary behaviour and screen time negatively affect children´s physical fitness and physical activity (Prince et al., 2024; Tremblay et al., 2011). Children, who met the physical activity recommendation had a higher cardiorespiratory endurance than those who did not. The same was found for screen time recommendations, which strongly influence sedentary behaviour of youth (Colley et al., 2019). However, recent evidence shows that most children are insufficiently physically active and do not meet these WHO recommended guidelines (Guthold et al., 2020; World Health Organization, 2022). Germanys Report Card on Physical Activity for Children and Adolescents also reported low levels of different types of physical activity (Demetriou et al., 2024). However, levels of physical activity have tended to remain stable in recent years, and levels of insufficient activity have decreased slightly since 2001 (Guthold et al., 2020; Schmidt, Anedda, Burchartz, Oriwol, et al., 2020; Woll et al., 2021; World Health Organization, 2022). More specifically, time spent in physical education levels remained stable and participation in organized forms of sport, i.e. sports clubs increased (Schmidt, Anedda, Burchartz, Oriwol, et al., 2020; Schmidt et al., 2017). These findings suggest direct coincidental trends that explain the recent slight increase and stagnation in physical fitness levels for the specific dimensions.

Body constitution is another factor with a strong influence on physical fitness and and physical activity is partly involved in this relationship (Ortega et al., 2010; Rauner et al., 2013; Stodden et al., 2008). Body constitution is a term that includes a variety of variables, but in the context of physical fitness, it refers specifically to BMI. (Barnett et al., 2022; Ortega et al., 2010). The effects of body constitution on physical fitness are obvious as we found significant negative quadratic trends for all test items, except flexibility. There is an optimum BMI with positive influence on the level of physical fitness. This is even more pronounced for endurance, speed and strength, where a high BMI is associated with a sharp decline in performance. In addition, mass is associated with better physical fitness, while height is not (Eberhardt, Bös, et al., submitted). This relationship between physical fitness and body constitution is well established (T. Olds & Dollman, 2004; Palomäki et al., 2015; Tomkinson et al., 2019). There has been much evidence in the literature of a rapid increase in overweight and obesity worldwide (NCD Risk Factor Collaboration, 2017; T. Olds et al., 2011; Y. Wang & Lobstein, 2006). However, the NCD Risk Factor Collaboration (2017) reported that the trend has recently plateaued, albeit at a high level. Similarly, the updated prevalence rate of overweight and obesity in Germany appears to be stagnating (Brettschneider et al., 2017). These largely congruent trends suggest that body composition, and in particular BMI, is a determinant of current trends in physical fitness, as their relationship has been empirically examined.

The occurrence of the COVID-19 pandemic at the beginning of 2020 came at an even more inopportune time, knowing that recently the declining trend in physical fitness has stopped and turned into stagnation. To limit the spread of the virus, countries have mainly implemented contact restrictions and closures. In Germany, nationwide closures were implemented twice and had a major impact on daily life(Schilling et al., 2021). The restrictions and subsequent consequences limited not only social life and behavioural routines, but also opportunities and structures for physical activity. Therefore, it is important to take them into account when examining trends in children's physical fitness. Several studies have already examined the influence of the COVID-19 pandemic on health aspects (Anderson et al., 2023; Wunsch et al., 2022). With regard to potential effects on physical fitness, this dissertation modeled secular trends in physical fitness for cohorts from 2012 to 2022 and additionally analysed COVID-pandemic related effects. There were significant negative effects of the pandemic as pre-pandemic trends changed negatively. However, the results vary for the different dimensions of physical fitness. In endurance, the negative effect was large enough to change the direction of the trend from slightly positive to negative (Eberhardt, Bös, et al., submitted). Teich et al. (2023) showed developmental delays of about 5 months due to pandemic effects on endurance, and this dimension appears to be the most affected (Basterfield et al., 2022; Chambonnière et al., 2021). Overall, strength also declined during the pandemic years, but there were differences depending body part examined and within the different studies. For the standing long jump, a negative change associated with the COVID-19 pandemic was found, but the effects of losses were weak (Chambonnière et al., 2021; Eberhardt, Bös, et al., submitted; Martinko et al., 2023). Sit-up performances, assessing trunk strength were worse during the pandemic and mainly the same appeared for upper body and upper limb strength with magnitude of changes being small (Chambonnière et al., 2021; Eberhardt, Bös, et al., submitted; Martinko et al., 2023; Teich et al., 2023). Findings for the test item Push-up are qualitatively different, as the pre-pandemic trend was initially interrupted and the level dropped, but the positive trend did not change afterwards and continued further on. In addition, we found no evidence of a change in trends due to the COVID-19 pandemic in coordination, suggesting that there are some dimensions that are less affected or not. Furthermore, some studies reported a recovery effect across pandemic years in some dimensions and children were able to quickly compensate some effects

(Jarnig et al., 2024; Martinko et al., 2023; Teich et al., 2023). Coordination seems to be less affected by negative influences compared to conditional abilities because the multifaceted nature of coordination with sensor-motor control allows for better mitigation by information-oriented aspects, such as cognitive processes (Bös & Mechling, 1983). In addition, strength may be more resilient to pandemic effects through modified physical activity routines during pandemic restrictions. We identified a specific sample and found no evidence of a negative effect of the COVID-19 pandemic on physical fitness in these children (Eberhardt et al., 2022). Overall, time in physical activity did not decrease significantly during the COVID-19 pandemic (Rossi et al., 2021; Wunsch et al., 2022). More specifically, there is the form of physical activity shifted to unorganized sports, mainly due to the closure of organized sports, such as physical education classes and sports clubs(Nigg et al., 2021; Schmidt, Anedda, Burchartz, Eichsteller, et al., 2020). In rural communities, physical activity may be maintained despite pandemic restrictions through opportunities for outdoor play and other alternatives (Nigg et al., 2021). The positive results for strength during the pandemic in the rural sample and that coordination is not affected by the impact, showed that even these forms are beneficial for some dimensions. Alternative options of online and indoor workouts mitigate the effects of the pandemic on children´s physical fitness and point to the importance of even small initiatives and promotion. Within the specific community, it is also evident that long-term programs and institutionalized promotion of physical activity have led to a high level of physical fitness compared to their national peers before the pandemic (Eberhardt et al., 2022). Higher levels of physical fitness support the mitigation of limited physical activity and break through the reciprocal cycle in these variables. Consistent with this, studies have reported higher levels of physical fitness among members of sports clubs (Basterfield et al., 2022; Jarnig et al., 2024). We emphasize the importance of regular and consistent engagement in promoting physical activity and physical fitness and note that they have a significant impact, particularly in the face of unpredictable events. Nevertheless, the development of physical fitness is a long-term and individual process influenced by various factors. The reported effects of the COVID-19 pandemic and changes in trends are still short-term. Therefore, the full extent of adaptations and potential impairments in physical fitness will not occur immediately.

However, as identified in the review conducted, there was a severe lack of research that meets the requirements for monitoring of current levels, trends and changes in physical fitness (Lang et al., 2023; Lopes et al., 2020). Within the research, inconsistent theoretical constructs for physical fitness are used, making comparability extremely difficult (Eberhardt et al., 2020; Fühner et al., 2021; Tomkinson et al., 2019). The varying results within each dimension of physical fitness indicate that specific attention is needed and that physical fitness as a multidimensional construct needs to be systematically investigated. Furthermore, there are various tools and instruments to assess physical fitness in children, based on the different approaches and guiding theories. On the one hand, this is positive because it provides the opportunity to find and select the most appropriate one. On the other hand, this is another lack of standardization that shows comparability over time and between populations (Brazo-Sayavera et al., 2024;

Marques et al., 2021). There is general consent on the need for a uniform test battery that can be used internationally, but the requirements and interests to this differ (Lang et al., 2023). Theoretically, test batteries can be either quantitative or qualitative assessment and therefore concerned with a product- or process-oriented approach. From a practical point of view, test batteries should be easy to conduct in the setting. As previously described, the GMT is based on the ability-oriented approach and assesses the latent abilities of physical fitness with measurable context-independent test items. It is designed for practical use in a variety of settings and is therefore economical and feasible. Our findings and analyses suggest that the quantitative assessment with the GMT s appropriate for examining current levels, trends, and changes in children's physical fitness because it considers children's development and is applicable across a wider age range, within different socio-cultural groups, and independent of time. This is particularly important because monitoring of trends needs to be long-term and regular. There are studies that monitor physical fitness in children by comparing separate measurement points. We suggest that this is not sufficient to determine trends of increasing, decreasing or stagnating levels of physical fitness over time. A long time between measurement points increases the possibility of changes over time, but does not achieve a reasonable development(Eberhardt et al., 2020). Therefore, regular and especially continuous assessment is essential. Measurement intervals should be close and over a long period of time. This is essential to make valid statements about trends in physical fitness and to ensure that relevant deviations, peaks and troughs are not overlooked. Certainly, there are already large data sets that meet the requirements and characteristics for monitoring and are scientifically reliable. However, analysing trends requires a large amount of data to exclude random results and to investigate clear cause-and-effect relationships with adequate statistical power. Individual studies with small numbers of children are often not considered because they are less generalizable (Clark & Whitall, 2021). By pooling existing data, sufficiently large samples over a continuous measurement period allowed a monitoring of trends and prevalence in physical fitness assessed with standardized test battery. In particular, with regard to the sudden onset of the COVID-19 pandemic, this allows for data-driven statements about the effects and changes in physical fitness levels in children. We presented how MO|RE data serve as specific infrastructure that provides a suitable solution (Eberhardt, et al., submitted). It allows us to proceed statistical analyses in a more exploratory way and to identify patterns of trends and changes, but also to state a current level of physical fitness of children. As a solution for pooling data of physical fitness, MO|RE data requires potential to address further existing research priorities (Lang et al., 2023). At the critical age of motor learning, even small changes and negative trends can have significant consequences for the long-term manifestation of physical fitness. Establishing a “proficiency barrier” or an adequate level of PF would help to monitor physical fitness in a more valid predictive way with regard to health-related development (Lopes et al., 2020; Malina, 2014). To develop and classify age- and sex-specific cut-off points and normative percentile values, a large database and sample within the MO|RE data could be used. These age- and sex-specific adjustments provide universal values of health-related development over time. In addition, the continuous nature of the normative values is useful for cross-sectional analyses (Köster et al., 2021; Niessner, Utesch, et al., 2020). Categorization into percentiles allows easy comparison of PF values with the reference group and with other samples that have used percentiles. It also allows for normative assessment and direct interpretation of results without the need to report additional statistical values. In the context of monitoring children's physical fitness, categorization makes the results more understandable to the population and for decision making, and is therefore particularly recommended for reporting results.

In order to establish a standardized test battery based on a common understanding of physical fitness, the reliability and validity of existing methodological approaches should be further investigated (Lang et al., 2023). Data pooling helps to assess the reliability and validity of fitness measures by providing a larger sample size and comprehensible database, allowing reliability and validity to be tested across different contexts, populations, and methods thus ensuring the robustness and generalizability of the test battery.

There are various variables and factors within the multifaceted construct of physical fitness and it is important to further understand and integrate them into analyses. Numerous studies have already examined the influences of the different determinants and correlates of physical fitness (Martinko et al., 2023; Nigg et al., 2022; Tomkinson et al., 2019). However, there is an urgent need for a more robust overview of these across different countries and cultural backgrounds to identify subgroups and hotspots. Pooling data from existing international studies within the MO|RE data would provide more evidence (Lopes et al., 2020).

The urgent need to translate research into practice was one of the purposes within this dissertation, but is also one of the greatest challenges (Green & Seifert, 2005; Lopes et al., 2020). From the limitations and challenges of reporting trends in children's physical fitness identified in the review, we have used data pooling with MO|RE data to overcome these and provide monitoring of the current situation, trends, and changes through data-driven analyses. However, the evidence-based findings will only have a practical impact if they are communicated to society, policy and decision makers, especially those responsible for further strategies to promote children's physical fitness. Therefore, we implemented the Fitness Barometer as a monitoring tool to disseminate data and related findings to relevant stakeholders (Eberhardt et al., 2021). Evidence-based public health monitoring aims to provide wisdom at the top of an informed pyramid for well-informed decisions (Verschuuren & Van Oers, 2020). Regular and systematic monitoring promotes improvements in physical fitness through the targeted processing of information through data. There are a few implemented physical fitness monitoring systems worldwide with different structures and designs. They are also characterized by the use of different test items and different constructs and wordings Some of them have already been implemented for a long time and operate in a school context, but the level of mandatory assessment of physical fitness is different. Integration into physical education classes allows for assessment of school-aged children across a wide age range and access to all children from different socioeconomic and cultural backgrounds (Joensuu et al., 2024). The Fitness Barometer data are collected on a voluntary basis and therefore depend on the motivation and willingness of individual institutions. We could benefit from several initiatives to promote physical fitness and awareness. Establishing a monitoring system is a long and complex process that involves a network of stakeholders. In cooperation with the Kinderturnstiftung Baden-Württemberg, a well-known and recognized foundation in this field, we have been publishing the Fitness Barometer annually for five years. The data pooling approach provides a large basic dataset with standardized values for children's physical fitness and allows for the annual addition of new data. Therefore, we could address some of the experience-based guidelines to design a physical fitness monitoring and surveillance system (Joensuu et al., 2024). Through workshops and events, we try to exchange ideas with practitioners and collect suggestions for improvement. The annual publication in a professional environment enables communication with experts and the public and helps to stimulate discussion. The Fitness Barometer provides meaningful feedback to those who evaluated the data and places the evidence-based findings in a broad context that is informative and targeted to different stakeholders. The use of percentiles and categories makes the results easy to understand and practical to categorize. From this, instructions for interpreting the results and further ideas for tailored activities were provided. By demonstrating the scientific background of the monitoring, we create trust and confidence in the data. Thus, the Fitness Barometer is the practical goal within this dissertation to monitor children's physical fitness levels, trends, and changes.

With regard to the informed consent pyramid, data as the basis of analyses are generated by reviewing the current state of research and by pooling together a large sufficient sample. This dissertation examined data on children's physical fitness in a comprehensible and data-driven manner to generate information on comparisons over time and between samples, and in particular on the impact of COVID-19. By placing the results in a broader context of the current state of research and other health variables, we developed possible explanations for patterns and findings. To translate this knowledge into evidence-based population health monitoring and to provide a scientific basis for decision making and further development of physical fitness promotion strategies, the Fitness Barometer was implemented.

A major strength of this work is the large data base and the methodological procedure of data pooling and subsequent data-driven analyses. Thus, we respected the multidimensional construct of children's physical fitness. We referred to a unified theoretical

construct of physical fitness and reported findings in a more specific manner. The occurrence of the COVID-19 pandemic revealed new challenges as it influenced physical fitness research worldwide, but also provided new opportunities for even more adequate work. By pooling data from different cohorts and identifying specific subsets worthy of further investigation, the main research questions were answered and clearly formulated. In order to make data pooling possible, intensive work was done to develop MO|RE data as a technical solution. We conducted a more exploratory and experimental analysis of the data using a data-driven approach. This allows us to systematically identify patterns within large samples. In addition to simpler statistical methods, we implemented a more complex linear mixed model with a regression discontinuity design to estimate different trends. Within this, fixed effects modeling provides estimates for specific variables that influence children's physical fitness. In addition, modeling random effects, which can bias the overall fit of the estimates, allows for more precise and generalizable estimation of trends. With the addition of a regression discontinuity design, we also aimed to integrate the COVID-19 pandemic as a quasi-experiment and detect potential changes in trends. By combining different statistical methods to analyse the data, the complexity of the influences on physical fitness was taken into account. Another strength of this dissertation is the realization of the public health aspect. Therefore, the fitness barometer is the best practice example, but also the results of the other papers presented a population health monitoring. By explicitly placing the scientific results in a broader context and reporting practical implications and further conclusions, we have been able to demonstrate how data-driven monitoring forms evidence-based practical value.

However, some limitations need to be discussed. The data pooling approach offers potential for analyses that require large data sets, but it also raises some methodological issues. By pooling a cross-sectional cohort, the analyses are based on an ad hoc sample and therefore the findings are not strictly representative and the generalizability of the results is limited. At the expense of homogeneity and better comparability, pooling tends to result in a loss of specific and individual information. There was no weighting of the various separate samples. Differences in the conditions and circumstances of the assessments were not controlled, and therefore some bias may have occurred within the analyses regarding confounders. In addition, measurement errors may have occurred for specific reasons. However, we believe that the large amount of data and number of measurements negate these potential limitations and that the findings are robust. The data-driven approach, as opposed to a theoretical and hypothesis-driven approach, offers a greater risk of overfitting due to a lack of theoretical foundation. Therefore, it is essential to thoroughly integrate findings into existing constructs and theories and contextualize them in the current literature.

In conclusion, we are convinced that pooling data and data-driven analyses are central methods in further monitoring of children´s physical fitness. The findings and suggestions gained in this dissertation are equally relevant for researches, decision-makers, and practitioners. From a scientific view, future research can build on the given findings regarding methodological purposes and further utilize MO|RE data to base analyses on sufficient large samples and examine them exploratory through trends and patterns. As practical value of this dissertation, the obtained evidence of current situation and influencing factors of children´s physical fitness can be used for population health monitoring to generate wisdom in actions and derive strategies and programs of promoting physical fitness in youth.

References

Ackoff, R. (1989). From Data to Wisdom. *Journal of Applied Systems Analysis*, *16*.

Albon, H. M., Hamlin, M. J., & Ross, J. J. (2010). Secular trends and distributional changes in health and fitness performance variables of 10-14-year-old children in New Zealand between 1991 and 2003. *British Journal of Sports Medicine*, *44*(4), 263–269. https://doi.org/10.1136/bjsm.2008.047142

Albrecht, C., Bös, K., Schlenker, L., Tobias, R., van Wasen, M., Weiß, N., & Woll, A. (2016). *Handreichung Forschungsdatenmanagement in der Sportwissenschaft*. Karlsruhe. https://doi.org/10.5445/IR/1000061538

Albrecht, C., Hanssen-Doose, A., Bös, K., Schlenker, L., Schmidt, S., Wagner, M., Will, N., & Worth, A. (2016). Motorische Leistungsfähigkeit von Kindern und Jugendlichen in Deutschland. *Sportwissenschaft*, *46*(4), 294–304.

https://doi.org/10.1007/s12662-016-0421-4

Albrecht, C., Oriwol, D., Hanssen-Doose, A., Woll, A., & Worth, A. (2018). German percentile curves of physical fitness from childhood to early adulthood- the MoMo-Study. In N. Anoke, L. Carmichael, N. Clarke, R. Copeland, D. Crone, J. L. Duda, B. Gardner, M. Hamer, M. Hillsdon, R. Hunter, R. Jago, T. Kay, M. Lewis, J. Mair, K. Milton, M. H. Murphy, N. Murphy, N. Mutrie, H. Rutter, … K. Wijndaele (Eds.), *7th International Society for Physical Activity and Health Congress* (Vol. 15, Issue Supplement 1, p. 50). Human Kinetics.

Alday, P. (2024). *palday/MixedModelsExtras.jl: V2.1.1* (Version v2.1.1) [Computer software]. Zenodo. https://doi.org/10.5281/ZENODO.10569543

Alday, P., Kliegl, R., & Bates, D. (2024). *Embrace the Uncertainty*. https://embraceuncertaintybook.com

Anderson, L. N., Yoshida-Montezuma, Y., Dewart, N., Jalil, E., Khattar, J., De Rubeis, V., Carsley, S., Griffith, L. E., & Mbuagbaw, L. (2023). Obesity and weight change during the COVID-19 pandemic in children and adults: A systematic review and meta-analysis. *Obesity Reviews*, *24*(5), e13550. https://doi.org/10.1111/obr.13550

Ao, D., Wu, F., Yun, C.-F., & Zheng, X.-Y. (2019). Trends in Physical Fitness Among 12-Year-Old Children in Urban and Rural Areas During the Social Transformation Period in China. *Journal of Adolescent Health*, *64*(2), 250–257. https://doi.org/10.1016/j.jadohealth.2018.08.021

Bähr, F., Wöhrl, T., Teich, P., Puta, C., & Kliegl, R. (2024). *Impact of Height-to-Mass Ratio on Physical Fitness of German Third-Grade Children*. https://doi.org/10.21203/rs.3.rs-3885133/v1

Bai, Y., Saint-Maurice, P. F., & Welk, G. J. (2017). Fitness Trends and Disparities Among School-Aged Children in Georgia, 2011-2014. *Public Health Reports*, *132*, 39S-47S. https://doi.org/10.1177/0033354917723911

Bardid, F., Vannozzi, G., Logan, S. W., Hardy, L. L., & Barnett, L. M. (2019). A hitchhiker's guide to assessing young people's motor competence: Deciding what method to use. *Journal of Science and Medicine in Sport*, *22*(3), 311–318. https://doi.org/10.1016/j.jsams.2018.08.007

Barnett, L. M., Webster, E. K., Hulteen, R. M., De Meester, A., Valentini, N. C., Lenoir, M., Pesce, C., Getchell, N., Lopes, V. P., Robinson, L. E., Brian, A., & Rodrigues, L. P. (2022). Through the Looking Glass: A Systematic Review of Longitudinal Evidence, Providing New Insight for Motor Competence and Health. *Sports Medicine*, *52*(4), 875–920. https://doi.org/10.1007/s40279-021-01516-8

Basterfield, L., Burn, N. L., Galna, B., Batten, H., Goffe, L., Karoblyte, G., Lawn, M., & Weston, K. L. (2022). Changes in children's physical fitness, BMI and health-related quality of life after the first 2020 COVID-19 lockdown in England: A longitudinal study. *Journal of Sports Sciences*, *40*(10), 1088–1096. https://doi.org/10.1080/02640414.2022.2047504

Bates, D., Alday, P., Kleinschmidt, D., Santiago Calderon, J. B., Zhan, L., Noack, A., Bouchet-Valat, M., Arslan, A., Kelman, T., Baldassari, A., Ehinger, B., Karrasch, D., Saba, E., Quinn, J., Hatherly, M., Piibeleht, M., Kofod Mogensen, P., Babayan, S., Holy, T., … Nazarathy, Y. (2024). *JuliaStats/MixedModels.jl: V4.23.1* (Version v4.23.1) [Computer software]. Zenodo. https://doi.org/10.5281/ZENODO.10871016

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2018). *Parsimonious Mixed Models* (arXiv:1506.04967). arXiv. https://doi.org/10.48550/arXiv.1506.04967

Baur, J., Bös, K., Conzelmann, A., & Singer, R. (Eds.). (2009). *Handbuch motorische Entwicklung* (2., komplett überarbeitete Aufl.). Hofmann.

Betancort Cabrera, N., Bongartz, E. C., Dörrenbächer, N., Goebel, J., Kaluza, H., & Siegers, P. (2020). White Paper on implementing the FAIR principles for data in the Social, Behavioural, and Economic Sciences. *RatSWD Working Paper Series*. https://doi.org/10.17620/02671.60

Betz, J. (2022). *Physical activity and motor performance of children during the Covid-19-pandemic using the example of the community of Michelfeld* [Unveröffentlichte Masterarbeit]. Karlsruher Insitut für Technologie.

Bezanson, J., Edelman, A., Karpinski, S., & Shah, V. B. (2017). Julia: A Fresh Approach to Numerical Computing. *SIAM Review*, *59*(1), 65–98. https://doi.org/10.1137/141000671

Bi, C., Zhang, F., Gu, Y., Song, Y., & Cai, X. (2020). Secular Trend in the Physical Fitness of Xinjiang Children and Adolescents between 1985 and 2014. *International Journal of Environmental Research and Public Health*, *17*(7), 2195. https://doi.org/10.3390/ijerph17072195

Boddy, L. M., Fairclough, S. J., Atkinson, G., & Stratton, G. (2012). Changes in Cardiorespiratory Fitness in 9- to 10.9-Year-Old Children: SportsLinx 1998–2010. *Medicine & Science in Sports & Exercise*, *44*(3), 481. https://doi.org/10.1249/MSS.0b013e3182300267

Bös, K. (1987). *Handbuch Sportmotorischer Tests*. Hogrefe.

Bös, K. (2003). Motorische Leistungsfähigkeit von Kindern. In W. Schmid, I. Hartmann-Tews, & W.-D. Brettschneider (Eds.), *Erster Deutscher Kinder- und Jugendsportbericht* (pp. 85–107). Hofmann.

Bös, K. (2016). *Deutscher Motorik Test 6-18 (DMT 6-18): Manual und internetbasierte Auswertungsplattform*. Feldhaus Edition Czwalina.

Bös, K. (Ed.). (2017). *Handbuch Motorische Tests: Sportmotorische Tests, Motorische Funktionstests, Fragebögen zur körperlich-sportlichen Aktivität und sportpsychologische Diagnoseverfahren* (3. überarbeitete und erweiterte Aufl.). Hogrefe.

Bös, K., Albrecht, C., Mewes, N., Tittlbach, S., & Woll, A. (2017). Aktivität und Fitness von Kindern und Jugendlichen: Unverzichtbar für die Gesundheit: Ergebnisse der MoMo-Studie. In R. Zimmer & I. Hunger (Eds.), *Gut starten: Bewegung—Entwicklung—Diversität*. Osnabrücker Kongress Bewegte Kindheit, Schorndorf. Hofmann.

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023a). *Fitnessbarometer BW 2013* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1706

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023b). *Fitnessbarometer BW 2014* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1705

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023c). *Fitnessbarometer BW 2015* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1704

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023d). *Fitnessbarometer BW 2016* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1703

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023e). *Fitnessbarometer BW 2017* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1701

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023f). *Fitnessbarometer BW 2018* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1702

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023g). *Fitnessbarometer BW 2019* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1711

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023h). *Fitnessbarometer BW 2020* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1713

Bös, K. & Kinderturnstiftung Baden-Württemberg. (2023i). *Fitnessbarometer BW 2021* [Dataset]. Motor Research Data Repository, Karlsruhe Institute of Technology. https://doi.org/10.35097/1714

Bös, K., Kloe, M., Daubenfeld, G., & Schlenker, L. (2020a). *Die Turnbeutelbande: Der Motorik-Test für Kinder. Testanleitung: Modul 1 Kindergartenalter* (Kinderturnstiftung Baden-Württemberg, Ed.; 2nd ed.). WIRmachenDRUCK GmbH.

Bös, K., Kloe, M., Daubenfeld, G., & Schlenker, L. (2020b). *Die Turnbeutelbande: Der Motorik-Test für Kinder. Testanleitung: Modul 2 Grundschulalter* (Kinderturnstiftung Baden-Württemberg, Ed.; 2nd ed.). WIRmachenDRUCK GmbH.

Bös, K., & Mechling, H. (1983). *Dimensionen sportmotorischer Leistungen*. Hofmann.

Bös, K., Oberger, J., Lämmle, L., Opper, E., Romahn, N., & Tittlbach, S. (2008). Motorische Leistungsfähigkeit von Kindern. In W. Schmidt & R. Zimmer (Eds.), *Zweiter Deutscher Kinder- und Jugendsportbericht: Schwerpunkt: Kindheit*. Hofmann.

Bös, K., Schlenker, L., Albrecht, Büsch, D., Lämmle, L., Müller, H., Oberger, J., Seidel, I., Tittlbach, S., & Woll, A. (with Schlenker, L., Albrecht, Büsch, D., Lämmle, L., Müller, H., Oberger, J., Seidel, I., Tittlbach, S., Woll, A., & Deutsche Vereinigung für Sportwissenschaft). (2009). *Deutscher Motorik-Test 6-18: Vol. Band 186* (1. Auflage). Feldhaus, Edition Czwalina.

Bös, K., Schlenker, L., Büsch, D., Eberhardt, T., Müller, H., Niessner, C., Tittlbach, S., & Woll, A. (2023). *Deutscher Motorik-Test 6-18: DMT 6-18* (3. Auflage, Vol. 186). Feldhaus Edition Czwalina.

Bös, K., Schlenker, L., Eberhardt, T., Abdelkarim, O., & Mechling, H. (2021). *International Physical Performance Test Profile 6-18 (revised): IPPTP-R (6-18)* (1. Auflage, Vol. 293). Feldhaus Edition Czwalina. https://doi.org/Klaus

Bös, K., & Ulmer, J. (2003). Motorische Entwicklung im Kindesalter. *Monatsschrift Kinderheilkunde*, *151*(1), 14–21. https://doi.org/10.1007/s00112-002-0623-8

Bouchard, C., Blair, S. N., & Haskell, W. L. (Eds.). (2012). *Physical activity and health* (2. ed). Human Kinetics.

Bouchard, C., Blair, S. N., & Katzmarzyk, P. T. (2015). Less Sitting, More Physical Activity, or Higher Fitness? *Mayo Clinic Proceedings*, *90*(11), 1533–1540. https://doi.org/10.1016/j.mayocp.2015.08.005

Bouchard, C., Shephard, R. J., & Brubaker, P. H. (1994). Physical Activity, Fitness, and Health: International Proceedings and Consensus Statement. *Medicine & Science in Sports & Exercise*, *26*(1), 119. https://doi.org/10.1249/00005768-199401000-00024

Brazo-Sayavera, J., Silva, D. R., Lang, J. J., Tomkinson, G. R., Agostinis-Sobrinho, C., Andersen, L. B., García-Hermoso, A., Gaya, A. R., Jurak, G., Lee, E.-Y., Liu, Y., Lubans, D. R., Okely, A. D., Ortega, F. B., Ruiz, J. R., Tremblay, M. S., & Dos Santos, L. (2024). Physical Fitness Surveillance and Monitoring Systems Inventory for Children and Adolescents: A Scoping Review with a Global Perspective. *Sports Medicine*. https://doi.org/10.1007/s40279-024-02038-9

Brettschneider, A.-K., Schienkiewitz, A., Schmidt, S. C. E., Ellert, U., & Kurth, B.-M. (2017). Updated prevalence rates of overweight and obesity in 4- to 10-year-old children in Germany.: Results from the telephone-based KiGGS Wave 1 after correction for bias in parental reports. *European Journal of Pediatrics*, *176*(4), 547–551. https://doi.org/10.1007/s00431-017-2861-8

Brownson, R. C., Fielding, J. E., & Maylahn, C. M. (2009). Evidence-Based Public Health: A Fundamental Concept for Public Health Practice. *Annual Review of Public Health*, *30*(1), 175–201. https://doi.org/10.1146/annurev.publhealth.031308.100134

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

Burton, A. W., & Miller, D. E. (1998). *Movement skill assessment*. Human Kinetics.

Büttner, S., Hobohm, H.-C., & Müller, L. (Eds.). (2011). *Handbuch Forschungsdatenmanagement*. BOCK+HERCHEN Verlag. https://doi.org/10.34678/OPUS4-208

Cadenas-Sanchez, C., Mena-Molina, A., Torres-Lopez, L. V., Migueles, J. H., Rodriguez-Ayllon, M., Lubans, D. R., & Ortega, F. B. (2021). Healthier Minds in Fitter Bodies: A Systematic Review and Meta-Analysis of the Association between Physical Fitness and Mental Health in Youth. *Sports Medicine (Auckland, N.Z.)*, *51*(12), 2571–2605. https://doi.org/10.1007/s40279-021-01520-y

Caspersen, C. J., Powell, K. E., & Christenson, G. M. (1985). Physical activity, exercise, and physical fitness: Definitions and distinctions for health-related research. *Public Health Reports*, *100*(2), 126–131.

Cattuzzo, M. T., Dos Santos Henrique, R., Ré, A. H. N., De Oliveira, I. S., Melo, B. M., De Sousa Moura, M., De Araújo, R. C., & Stodden, D. (2016). Motor competence and health related physical fitness in youth: A systematic review. *Journal of Science and Medicine in Sport*, *19*(2), 123–129. https://doi.org/10.1016/j.jsams.2014.12.004

Chambonnière, C., Fearnbach, N., Pelissier, L., Genin, P., Fillon, A., Boscaro, A., Bonjean, L., Bailly, M., Siroux, J., Guirado, T., Pereira, B., Thivel, D., & Duclos, M. (2021). Adverse Collateral Effects of COVID-19 Public Health Restrictions on Physical Fitness and Cognitive Performance in Primary School Children. *International Journal of Environmental Research and Public Health*, *18*(21). https://doi.org/10.3390/ijerph182111099

Chen, G., Chen, J., Liu, J., Hu, Y., & Liu, Y. (2022). Relationship between body mass index and physical fitness of children and adolescents in Xinjiang, China: A cross-sectional study. *BMC Public Health*, *22*(1), 1680. https://doi.org/10.1186/s12889-022-14089-6

Clark, J. E. (2002). The Mountain of Motor Development: A Metaphor. In J. E. Clark & J. Humphrey (Eds.), *Motor development: Research and reviews* (pp. 163–190). NASPE Publications.

Clark, J. E., & Humphrey, J. H. (Eds.). (2002). *Motor Development: Research and Reviews* (2nd ed.). National Association for Sport and Physical Education.

Clark, J. E., & Whitall, J. (2021). Motor Development: A Perspective on the Past, the Present, and the Future. *Kinesiology Review*, *10*(3), 264–273. https://doi.org/10.1123/kr.2021-0023

Cliff, D. P., Hesketh, K. D., Vella, S. A., Hinkley, T., Tsiros, M. D., Ridgers, N. D., Carver, A., Veitch, J., Parrish, A.-M., Hardy, L. L., Plotnikoff, R. C., Okely, A. D., Salmon, J., & Lubans, D. R. (2016). Objectively measured sedentary behaviour and health and development in children and adolescents: Systematic review and meta-analysis. *Obesity Reviews*, *17*(4), 330–344. https://doi.org/10.1111/obr.12371

Cochrane, T., Davey, R. C., & De Castella, F. R. (2015). Influence of school community and fitness on prevalence of overweight in Australian school children. *Preventive Medicine*, *81*, 433–437. https://doi.org/10.1016/j.ypmed.2015.10.013

Cohen, D., Voss, C., Taylor, M., Delextrat, A., Ogunleye, A., & Sandercock, G. (2011). Ten-year secular changes in muscular fitness in English children. *Acta Paediatrica*, *100*(10), e175–e177. https://doi.org/10.1111/j.1651-2227.2011.02318.x

Colley, R., Clarke, J., Janssen, I., Doyon, C. Y., Lang, J. J., Tremblay, M. S., & Timmons, B. W. (2019). Trends in physical fitness among Canadian children and youth. *Health Reports*, *30*(10), 3–13. https://doi.org/10.25318/82-003-X201901000001-ENG

Costa, A. M., Costa, M. J., Reis, A. A., Ferreira, S., Martins, J., & Pereira, A. (2017). Secular Trends in Anthropometrics and Physical Fitness of Young Portuguese School-Aged Children. *Acta Medica Portuguesa*, *30*(2), 108–114. https://doi.org/10.20344/amp.7712

DataCite Metadata Working Group. (2021). *DataCite Metadata Schema Documentation for the Publication and Citation of Research Data and Other Research Outputs v4.4*. DataCite. https://doi.org/10.14454/3W3Z-SA82

Daymont, C., Ross, M. E., Russell Localio, A., Fiks, A. G., Wasserman, R. C., & Grundmeier, R. W. (2017). Automated identification of implausible values in growth data from pediatric electronic health records. *Journal of the American Medical Informatics Association*, *24*(6), 1080–1087. https://doi.org/10.1093/jamia/ocx037

Demetriou, Y., Beck, F., Sturm, D., Abu-Omar, K., Forberger, S., Hebestreit, A., Hohmann, A., Hülse, H., Kläber, M., Kobel, S., Köhler, K., König, S., Krug, S., Manz, K., Messing, S., Mutz, M., Niermann, C., Niessner, C., Schienkiewitz, A., Reimers, A. K. (2024). Germany’s 2022 Report Card on Physical Activity for Children and Adolescents. *German Journal of Exercise and Sport Research*, 1–16. https://doi.org/10.1007/s12662-024-00946-6

Ding, P. (2019). Application of Big Data in Sports Science and Reflections. *Journal of Physics: Conference Series*, *1302*(4), 042048. https://doi.org/10.1088/1742-6596/1302/4/042048

Dong, Y., Lau, P. W. C., Dong, B., Zou, Z., Yang, Y., Wen, B., Ma, Y., Hu, P., Song, Y., Ma, J., Sawyer, S. M., & Patton, G. C. (2019). Trends in physical fitness, growth, and nutritional status of Chinese children and adolescents: A retrospective analysis of 1·5 million students from six successive national surveys between 1985 and 2014. *The Lancet Child & Adolescent Health*, *3*(12), 871–880. https://doi.org/10.1016/S2352-4642(19)30302-5

Dos Santos, F. K., Prista, A., Gomes, T. N. Q. F., Daca, T., Madeira, A., Katzmarzyk, P. T., & Maia, J. A. R. (2015). Secular trends in physical fitness of Mozambican school-aged children and adolescents. *American Journal of Human Biology*, *27*(2), 201–206. https://doi.org/10.1002/ajhb.22638

Drenowatz, C., Ferrari, G., Greier, K., Chen, S., & Hinterkörner, F. (2023). Physical fitness in Austrian elementary school children prior to and post-COVID-19. *AIMS Public Health*, *10*(2), 480–495. https://doi.org/10.3934/publichealth.2023034

Drozdowska, A., Falkenstein, M., Jendrusch, G., Platen, P., Lücke, T., Kersting, M., & Sinningen, K. (2021). Interrelations of Physical Fitness and Cognitive Functions in German Schoolchildren. *Children*, *8*(8), 669. https://doi.org/10.3390/children8080669

Dwyer, T., Magnussen, C. G., Schmidt, M. D., Ukoumunne, O. C., Ponsonby, A.-L., Raitakari, O. T., Zimmet, P. Z., Blair, S. N., Thomson, R., Cleland, V. J., & Venn, A. (2009). Decline in physical fitness from childhood to adulthood associated with increased obesity and insulin resistance in adults. *Diabetes Care*, *32*(4), 683–687.

https://doi.org/10.2337/dc08-1638

Dyrstad, S. M., Berg, T., & Tjelta, L. I. (2012). Secular trends in aerobic fitness performance in a cohort of Norwegian adolescents. *Scandinavian Journal of Medicine & Science in Sports*, *22*(6), 822–827. https://doi.org/10.1111/j.1600-0838.2011.01315.x

Eberhardt, T., Bös, K., & Niessner, C. (2021). The Fitness Barometer: A Best Practice Example for Monitoring Motor Performance With Pooled Data Collected From Practitioners. *Frontiers in Public Health*, *9*, 720589. https://doi.org/10.3389/fpubh.2021.720589

Eberhardt, T., Bös, K., & Niessner, C. (2022). Changes in Physical Fitness during the COVID-19 Pandemic in German Children. *International Journal of Environmental Research and Public Health*, *19*(15). https://doi.org/10.3390/ijerph19159504

Eberhardt, T., Bös, K., Woll, A., Kliegl, R., & Niessner, C. (submitted). Secular Trends of Children´s Physical Fitness and COVID-Pandemic Impact for Years 2012 to 2022. *Sports Medicine - Open*.

Eberhardt, T., Keller, K., Zimmermann, H., Schlenker, L., Bös, K., & Niessner, C. (submitted). The Potential of Data Pooling with Open Data Infrastructures in Motor Performance Research—A Discussion Based on the Example of MORE data. *German Journal of Exercise and Sport Research*.

Eberhardt, T., Kron, H., Katterloher, T., & Klemm, K. (2023). Diagnostik der motorischen Leistungsfähigkeit in der Schule – Vermitteln, Messen und Anwenden. *Sportpraxis*, *64*(1).

Eberhardt, T., Niessner, C., Oriwol, D., Buchal, L., Worth, A., & Bös, K. (2020). Secular Trends in Physical Fitness of Children and Adolescents: A Review of Large-Scale Epidemiological Studies Published after 2006. *International Journal of Environmental Research and Public Health*, *17*(16). https://doi.org/10.3390/ijerph17165671

Ekblom, Ö. B., Ekblom Bak, E. A., & Ekblom, B. T. (2011). Cross-sectional trends in cardiovascular fitness in Swedish 16-year-olds between 1987 and 2007. *Acta Paediatrica*, *100*(4), 565–569. https://doi.org/10.1111/j.1651-2227.2010.02135.x

Fang, K., Mu, M., Liu, K., & He, Y. (2019). Screen time and childhood overweight/obesity: A systematic review and meta-analysis. *Child: Care, Health and Development*, *45*(5), 744–753. https://doi.org/10.1111/cch.12701

Finger, J. D., Varnaccia, G., Borrmann, A., Lange, C., & Mensink, G. B. M. (2018). Körperliche Aktivität von Kindern und Jugendlichen in Deutschland – Querschnittergebnisse aus KiGGS Welle 2 und Trends. *Journal of Health Monitoring*, *3*(1), 24–31. https://doi.org/10.17886/RKI-GBE-2018-006.2

Fraser, B. J., Blizzard, L., Buscot, M.-J., Schmidt, M. D., Dwyer, T., Venn, A. J., & Magnussen, C. G. (2021). Muscular strength across the life course: The tracking and trajectory patterns of muscular strength between childhood and mid-adulthood in an Australian cohort. *Journal of Science and Medicine in Sport*, *24*(7), 696–701. https://doi.org/10.1016/j.jsams.2021.01.011

Fraser, B. J., Blizzard, L., Tomkinson, G. R., Lycett, K., Wake, M., Burgner, D., Ranganathan, S., Juonala, M., Dwyer, T., Venn, A. J., Olds, T., & Magnussen, C. G. (2019). The great leap backward: Changes in the jumping performance of Australian children aged 11−12-years between 1985 and 2015. *Journal of Sports Sciences*, *37*(7), 748–754. https://doi.org/10.1080/02640414.2018.1523672

Fühner, T., Kliegl, R., Arntz, F., Kriemler, S., & Granacher, U. (2021). An Update on Secular Trends in Physical Fitness of Children and Adolescents from 1972 to 2015: A Systematic Review. *Sports Medicine (Auckland, N.Z.)*, *51*(2), 303–320. https://doi.org/10.1007/s40279-020-01373-x

Gallahue, D. L., Ozmun, J. C., & Goodway, J. D. (2019). *Understanding Motor Development: Infants, Children, Adolescents, Adults*. Jones & Bartlett Learning.

García-Hermoso, A., Izquierdo, M., & Ramírez-Vélez, R. (2022). Tracking of physical fitness levels from childhood and adolescence to adulthood: A systematic review and meta-analysis. *Translational Pediatrics*, *11*(4), 474–486. https://doi.org/10.21037/tp-21-507

García-Hermoso, A., Ramírez-Campillo, R., & Izquierdo, M. (2019). Is Muscular Fitness Associated with Future Health Benefits in Children and Adolescents? A Systematic Review and Meta-Analysis of Longitudinal Studies. *Sports Medicine (Auckland, N.Z.)*, *49*(7), 1079–1094. https://doi.org/10.1007/s40279-019-01098-6

Gerlach, E., Herrmann, C., Jekauc, D., & Wagner, M. (2017). Diagnostik motorischer Leistungsdispositionen. In U. Trautwein & M. Hasselhorn (Eds.), *Begabungen und Talente* (Vol. 15). Hogrefe.

Giuriato, M., Carnevale Pellino, V., Cavallo, C., Farronato, L., Pirazzi, A., Beghetto, A., Gross, F., Del Bianco, M., Gatti, A., Vandoni, M., & Lovecchio, N. (2023). Physical fitness trend after COVID-19 restrictions in Italian school-aged children: A cross-sectional study. *The Journal of Sports Medicine and Physical Fitness*, *63*(9), 995–1002. https://doi.org/10.23736/S0022-4707.23.14943-7

Green, L. A., & Seifert, C. M. (2005). Translation of Research Into Practice: Why We Can't "Just Do It." *The Journal of the American Board of Family Medicine*, *18*(6), 541–545. https://doi.org/10.3122/jabfm.18.6.541

Greier, K., Drenowatz, C., Ruedl, G., Lackner, C., Kroell, K., & Feurstein-Zerlauth, V. (2018). Differences in Motor Competence by TV Consumption and Participation in Club Sports in Children Starting Elementary School. *International Journal of School Health*, *In Press*(In Press). https://doi.org/10.5812/intjsh.68454

Greier, K., Riechelmann, H., Ruedl, G., & Drenowatz, C. (2019). Changes in motor competence over four decades in 10 to 14-year-old Austrian boys. *Current Issues in Sport Science (CISS)*, *4*, 012–012. https://doi.org/10.15203/CISS_2019.012

Gu, X., Zhang, T., Chu, T. L. A., Keller, M. J., & Zhang, X. (2019). The direct and indirect effects of motor competence on adolescents' mental health through health-related physical fitness. *Journal of Sports Sciences*, *37*(17), 1927–1933. https://doi.org/10.1080/02640414.2019.1605652

Guthold, R., Stevens, G. A., Riley, L. M., & Bull, F. C. (2020). Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1·6 million participants. *The Lancet Child & Adolescent Health*, *4*(1), 23–35. https://doi.org/10.1016/S2352-4642(19)30323-2

Hales, C. M., Freedman, D., Akinbami, L., Wei, R., & Ogden, C. (2022). *Evaluation of alternative body mass index (BMI) metrics to monitor weight status in children and adolescents with extremely high BMI using CDC BMI-for-age growth charts*. National Center for Health Statistics (U.S.). https://doi.org/10.15620/cdc:121711

Hamer, M., O'Donovan, G., Batty, G. D., & Stamatakis, E. (2020). Estimated cardiorespiratory fitness in childhood and cardiometabolic health in adulthood: 1970 British Cohort Study. *Scandinavian Journal of Medicine & Science in Sports*, *30*(5), 932–938. https://doi.org/10.1111/sms.13637

Hänsel, F. (2008). Kognitive Aspekte. In A. Conzelmann & F. Hänsel (Eds.), *Sport und Selbstkonzept: Struktur, Dynamik und Entwicklung* (pp. 26–44). Hofmann.

Hanssen-Doose, A., Niessner, C., Oriwol, D., Bös, K., Woll, A., & Worth, A. (2021). Population-based trends in physical fitness of children and adolescents in Germany, 2003-2017. *European Journal of Sport Science*, *21*(8), 1204–1214. https://doi.org/10.1080/17461391.2020.1793003

Hardy, L. L., Merom, D., Thomas, M., & Peralta, L. (2018). 30-year changes in Australian children's standing broad jump: 1985–2015. *Journal of Science and Medicine in Sport*, *21*(10), 1057–1061. https://doi.org/10.1016/j.jsams.2018.04.005

Henriksson, P., Shiroma, E. J., Henriksson, H., Tynelius, P., Berglind, D., Löf, M., Lee, I.-M., & Ortega, F. B. (2021). Fit for life? Low cardiorespiratory fitness in adolescence is associated with a higher burden of future disability. *British Journal of Sports Medicine*, *55*(3), 128–129. https://doi.org/10.1136/bjsports-2020-102605

Huotari, P. R. T., Nupponen, H., Laakso, L., & Kujala, U. M. (2010). Secular trends in muscular fitness among Finnish adolescents. *Scandinavian Journal of Public Health*, *38*(7), 739–747. https://doi.org/10.1177/1403494810384425

Jaakkola, T., Yli-Piipari, S., Huotari, P., Watt, A., & Liukkonen, J. (2016). Fundamental movement skills and physical fitness as predictors of physical activity: A 6-year follow-up study. *Scandinavian Journal of Medicine & Science in Sports*, *26*(1), 74–81. https://doi.org/10.1111/sms.12407

Jarnig, G., Jaunig, J., & van Poppel, M. N. M. (2021). Association of COVID-19 Mitigation Measures With Changes in Cardiorespiratory Fitness and Body Mass Index Among Children Aged 7 to 10 Years in Austria. *JAMA Network Open*, *4*(8), 2121675. https://doi.org/10.1001/jamanetworkopen.2021.21675

Jarnig, G., Kerbl, R., & Van Poppel, M. N. M. (2024). Changes in children's cardiorespiratory fitness and body mass index over the course of the COVID-19 pandemic: A 34-month longitudinal study of 331 primary school children. *World Journal of Pediatrics*, *20*(2), 185–188. https://doi.org/10.1007/s12519-023-00772-0

Jekauc, D., Reimers, A. K., & Woll, A. (2014). Methoden der Aktivitätsmessung bei Kindern und Jugendlichen. *B&G Bewegungstherapie Und Gesundheitssport*, *30*(02), 79–82. https://doi.org/10.1055/s-0033-1361578

Joensuu, L., Csányi, T., Huhtiniemi, M., Kälbi, K., Magalhães, J., Milanović, I., Morrison, S. A., Ortega, F. B., Sardinha, L. B., Starc, G., Tammelin, T. H., Jurak, G., & the FitBack Network. (2024). How to design and establish a national school-based physical fitness monitoring and surveillance system for children and adolescents: A 10-step approach recommended by the FitBack network. *Scandinavian Journal of Medicine & Science in Sports*, *34*(3), e14593. https://doi.org/10.1111/sms.14593

Jürimäe, T., Volbekiene, V., Jürimäe, J., & Tomkinson, G. R. (2007). *Changes in Eurofit Test Performance of Estonian and Lithuanian Children and Adolescents (1992–2002)*. https://doi.org/10.1159/000101356

Karlsruhe Institute of Technology. (2023). *MO|RE data*. https://motor-research-data.de

Kinderturnstiftung Baden-Württemberg. (2019). *Fitnessbarometer 2019*. https://www.turnbeutelbande.de/wp-content/uploads/Factsheet_Fitnessbarometer-2019.pdf

Kinderturnstiftung Baden-Württemberg. (2020). *Fitnessbarometer 2020*. https://www.kinderturnstiftung-bw.de/wp-content/uploads/2020/06/Factsheet-Fitnessbarometer-2020.pdf

Kinderturnstiftung Baden-Württemberg. (2021). *Fitnessbarometer 2021*. https://www.turnbeutelbande.de/wp-content/uploads/Factsheet-Fitnessbarometer-2021.pdf

Kinderturnstiftung Baden-Württemberg. (2022). *Fitnessbarometer 2022*. https://www.turnbeutelbande.de/wp-content/uploads/Factsheet-Fitnessbarometer-2022.pdf

Kinderturnstiftung Baden-Württemberg. (2023). *Fitnessbarometer 2023*. https://www.kinderturnstiftung-bw.de/wp-content/uploads/2023/06/Factsheet-Fitnessbarometer-2023-kleine-Aufloesung.pdf

Kinderturnstiftung Baden-Württemberg (Ed.). (2024). *Fitnessbarometer 2024*. https://www.kinderturnstiftung-bw.de/wp-content/uploads/2023/03/Das-Fitnessbarometer-2024_final.pdf

Klemm, K., Bös, K., Kron, H., Eberhardt, T., Woll, A., & Niessner, C. (2024). Development and Introduction of a Disciplinary Data Repository for Sport Scientists Based on the Example MO|RE Data [Application/pdf]. *Bausteine Forschungsdatenmanagement*, *1*, 1–14. https://doi.org/10.17192/BFDM.2024.1.8615

Kloe, M. (2021). *Open Data im sportwissenschaftlichen Anwendungsfeld motorischer Tests: Theoretische, methodische und praxisbezogene Aspekte*. Karlsruher Institut für Technologie (KIT). https://doi.org/10.5445/IR/1000129767

Kloe, M., Niessner, C., Daubenfeld, G., & Bös, K. (2020). Der Fitnessbarometer – Eine Methode für ein Bewegungsmonitoring von Kindern am Beispiel von gepoolten Daten aus Baden-Württemberg. *Leipziger Sportwissenschaftliche Beiträge*, *61*(1), 104–127.

Kloe, M., Niessner, C., Woll, A., & Bös, K. (2019). Open Data im sportwissenschaftlichen Anwendungsfeld motorischer Tests. *German Journal of Exercise and Sport Research*, *49*(4), 503–513. https://doi.org/10.1007/s12662-019-00620-2

Kloe, M., Oriwol, D., Niessner, C., Worth, A., & Bös, K. (2020). Wie leistungsfähig sind meine Schüler_innen? Leistungsbeurteilung mittels Referenzperzentilen zu den Testaufgaben 20-m-Sprint und 6-Minuten-Lauf. *Sportunterricht*, *69*, 386–392.

Köster, P., Hohmann, A., Niessner, C., & Siener, M. (2021). Health-Related Motor Testing of Children in Primary School: A Systematic Review of Criterion-Referenced Standards. *Children (Basel, Switzerland)*, *8*(11), 1046. https://doi.org/10.3390/children8111046

Kreutzer, T., & Lahmann, H. C. (with Kaulen, I.). (2021). *Rechtsfragen bei Open Science: Ein Leitfaden* (2., überarbeitete und erweiterte Auflage). Hamburg University Press, Verlag der Staats- und Universitätsbibliothek Hamburg. https://doi.org/10.15460/HUP.211

Kromeyer-Hauschild, K., Wabitsch, M., Kunze, D., Geller, F., Geiß, H. C., Hesse, V., Hippel, A., Jaeger, U., Johnsen, D., Korte, W., Menner, K., Müller, G., Müller, J. M., Niemann-Pilatus, A., Remer, T., Schaefer, F., Wittchen, H.-U., Zabransky, S., Zellner, K., Hebebrand, J. (2001). Perzentile für den Body-mass-Index für das Kindes- und

Jugendalter unter Heranziehung verschiedener deutscher Stichproben. *Monatsschrift Kinderheilkunde*, *149*(8), 807–818. https://doi.org/10.1007/s001120170107

Krüger, M., Biniossek, C., Stocker, M., & Betz, D. (2023). Perspektives and Potentials of Open Data for the Sports Sciences: The “What”, the “Why”, and the “How.” *Zeitschrift Für Sportpsychologie*, *30*(4), 167–176. https://doi.org/10.1026/1612-5010/a000405

Kwieciński, J., Konarski, J. M., Strzelczyk, R., Krzykała, M., Konarska, A., Bartkowiak, S., Lopes, V., & Malina, R. M. (2018). Non-linear relationships between the BMI and physical fitness in Polish adolescents. *Annals of Human Biology*, *45*(5), 406–413. https://doi.org/10.1080/03014460.2018.1494306

Lämmle, L., Tittlbach, S., Oberger, J., Worth, A., & Bös, K. (2010). A Two-level Model of Motor Performance Ability. *Journal of Exercise Science & Fitness*, *8*(1), 41–49. https://doi.org/10.1016/S1728-869X(10)60006-8

Lang, J. J., Tomkinson, G. R., Janssen, I., Ruiz, J. R., Ortega, F. B., Léger, L., & Tremblay, M. S. (2018). Making a Case for Cardiorespiratory Fitness Surveillance Among Children and Youth. *Exercise and Sport Sciences Reviews*, *46*(2), 66–75. https://doi.org/10.1249/JES.0000000000000138

Lang, J. J., Zhang, K., Agostinis-Sobrinho, C., Andersen, L. B., Basterfield, L., Berglind, D., Blain, D. O., Cadenas-Sanchez, C., Cameron, C., Carson, V., Colley, R. C., Csányi, T., Faigenbaum, A. D., García-Hermoso, A., Gomes, T. N. Q. F., Gribbon, A., Janssen, I., Jurak, G., Kaj, M., … Fraser, B. J. (2023). Top 10 International Priorities for Physical Fitness Research and Surveillance Among Children and Adolescents: A Twin-Panel Delphi Study. *Sports Medicine (Auckland, N.Z.)*, *53*(2), 549–564. https://doi.org/10.1007/s40279-022-01752-6

Larsen, L. R., Kristensen, P. L., Junge, T., Rexen, C. T., & Wedderkopp, N. (2015). Motor Performance as Predictor of Physical Activity in Children: The CHAMPS Study-DK. *Medicine & Science in Sports & Exercise*, *47*(9), 1849–1856. https://doi.org/10.1249/MSS.0000000000000604

LeBlanc, A. G., Gunnell, K. E., Prince, S. A., Saunders, T. J., Barnes, J. D., & Chaput, J.-P. (2017). The Ubiquity of the Screen: An Overview of the Risks and Benefits of Screen Time in Our Modern World. *Translational Journal of the American College of Sports Medicine*, *2*(17). https://journals.lww.com/acsm-tj/Fulltext/2017/09010/The_Ubiquity_of_the_Screen__An_Overview_of_the.1.aspx

Lee, D. S., & Lemieux, T. (2010). Regression discontinuity designs in economics. *Journal of Economic Literature*, *48*, 281–355.

Lee, E.-J., Seo, D.-I., Lee, S.-M., & Kim, J.-H. (2022). Changes in Physical Fitness among Elementary and Middle School Students in Korea before and after COVID-19. *International Journal of Environmental Research and Public Health*, *19*(18). https://doi.org/10.3390/ijerph191811712

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A., Clarke, M., Devereaux, P. J., Kleijnen, J., & Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: Explanation and elaboration. *BMJ*, *339*, b2700. https://doi.org/10.1136/bmj.b2700

Lima, R. A., Soares, F. C., Queiroz, D. R., Aguilar, J. A., Bezerra, J., & Barros, M. V. G. (2021). The importance of body weight status on motor competence development: From preschool to middle childhood. *Scandinavian Journal of Medicine & Science in Sports*, *31 Suppl 1*, 15–22. https://doi.org/10.1111/sms.13787

Logan, S. W., Ross, S. M., Chee, K., Stodden, D. F., & Robinson, L. E. (2018). Fundamental motor skills: A systematic review of terminology. *Journal of Sports Sciences*, *36*(7), 781–796. https://doi.org/10.1080/02640414.2017.1340660

Lopes, L., Santos, R., Coelho-E-Silva, M., Draper, C., Mota, J., Jidovtseff, B., Clark, C., Schmidt, M., Morgan, P., Duncan, M., O'Brien, W., Bentsen, P., D'Hondt, E., Houwen, S., Stratton, G., Martelaer, K., Scheuer, C., Herrmann, C., García-Hermoso, A., … Agostinis-Sobrinho, C. (2020). A Narrative Review of Motor Competence in Children and Adolescents: What We Know and What We Need to Find Out. *International Journal of Environmental Research and Public Health*, *18*(1). https://doi.org/10.3390/ijerph18010018

Lubans, D. R., Morgan, P. J., Cliff, D. P., Barnett, L. M., & Okely, A. D. (2010). Fundamental movement skills in children and adolescents: Review of associated health benefits. *Sports Medicine*, *40*(12), 1019–1035. https://doi.org/10.2165/11536850-000000000-00000

Lüdecke, D., Patil, I., Ben-Shachar, M., Wiernik, B., Bacher, E., Thériault, R., & Makowski, D. (2022). easystats: Framework for Easy Statistical Modeling, Visualization, and Reporting. *CRAN*. https://doi.org/10.21105/joss.01686

Maass, W., Parsons, J., Memorial University of Newfoundland, Purao, S., Bentley University, Storey, V. C., Georgia State University, Woo, C., & University of British Columbia. (2018). Data-Driven Meets Theory-Driven Research in the Era of Big Data: Opportunities and Challenges for Information Systems Research. *Journal of the Association for Information Systems*, 1253–1273. https://doi.org/10.17705/1jais.00526

Malina, R. M. (2014). Top 10 Research Questions Related to Growth and Maturation of Relevance to Physical Activity, Performance, and Fitness. *Research Quarterly for Exercise and Sport*, *85*(2), 157–173. https://doi.org/10.1080/02701367.2014.897592

Marques, A., Henriques-Neto, D., Peralta, M., Martins, J., Gomes, F., Popovic, S., Masanovic, B., Demetriou, Y., Schlund, A., & Ihle, A. (2021). Field-Based Health-Related Physical Fitness Tests in Children and Adolescents: A Systematic Review. *Frontiers in Pediatrics*, *9*, 640028. https://doi.org/10.3389/fped.2021.640028

Martinko, A., Sorić, M., Jurak, G., & Starc, G. (2023). Physical fitness among children with diverse weight status during and after the COVID-19 pandemic: A population-wide, cohort study based on the Slovenian physical fitness surveillance system (SLOfit). *The*

Lancet Regional Health - Europe, *34*, 100748. https://doi.org/10.1016/j.lanepe.2023.100748

Masanovic, B., Gardasevic, J., Marques, A., Peralta, M., Demetriou, Y., Sturm, D. J., & Popovic, S. (2020). Trends in Physical Fitness Among School-Aged Children and Adolescents: A Systematic Review. *Frontiers in Pediatrics*, *8*, 627529. https://doi.org/10.3389/fped.2020.627529

Matton, L., Duvigneaud, N., Wijndaele, K., Philippaerts, R., Duquet, W., Beunen, G., Claessens, A. L., Thomis, M., & Lefevre, J. (2007). Secular trends in anthropometric characteristics, physical fitness, physical activity, and biological maturation in Flemish adolescents between 1969 and 2005. *American Journal of Human Biology*, *19*(3), 345–357. https://doi.org/10.1002/ajhb.20592

Matuschek, H., Kliegl, R., Vasishth, S., Baayen, H., & Bates, D. (2017). Balancing Type I Error and Power in Linear Mixed Models. *Journal of Memory and Language*, *94*, 305–315. https://doi.org/10.1016/j.jml.2017.01.001

McKiernan, E. C., Bourne, P. E., Brown, C. T., Buck, S., Kenall, A., Lin, J., McDougall, D., Nosek, B. A., Ram, K., Soderberg, C. K., Spies, J. R., Thaney, K., Updegrove, A., Woo, K. H., & Yarkoni, T. (2016). How open science helps researchers succeed. *eLife*, *5*, e16800. https://doi.org/10.7554/eLife.16800

Moliner-Urdiales, D., Ruiz, J. R., Ortega, F. B., Jiménez-Pavón, D., Vicente-Rodriguez, G., Rey-López, J. P., Martínez-Gómez, D., Casajús, J. A., Mesana, M. I., Marcos, A., Noriega-Borge, M. J., Sjöström, M., Castillo, M. J., Moreno, L. A., & AVENA and HELENA Study Groups. (2010). Secular trends in health-related physical fitness in Spanish adolescents: The AVENA and HELENA studies. *Journal of Science and Medicine in Sport*, *13*(6), 584–588. https://doi.org/10.1016/j.jsams.2010.03.004

Moraes Ferrari, G. L. de, Bracco, M. M., Matsudo, V. K. R., & Fisberg, M. (2013). Cardiorespiratory fitness and nutritional status of schoolchildren: 30-year evolution. *Jornal De Pediatria*, *89*(4), 366–373. https://doi.org/10.1016/j.jped.2012.12.006

Morales-Demori, R., Jamil, O., & Serratto, M. (2017). Trend of Endurance Level Among Healthy Inner-City Children and Adolescents Over Three Decades. *Pediatric Cardiology*, *38*(1), 123–127. https://doi.org/10.1007/s00246-016-1492-6

Müllerová, D., Langmajerová, J., Sedláček, P., Dvořáková, J., Hirschner, T., Weber, Z., Müller, L., & Derflerová Brázdová, Z. (2015). Dramatic decrease in muscular fitness in Czech schoolchildren over the Last 20 years. *Central European Journal of Public Health*, *23*(Supplement), S9–S13. https://doi.org/10.21101/cejph.a4069

Munafò, M. R., Nosek, B. A., Bishop, D. V. M., Button, K. S., Chambers, C. D., Percie Du Sert, N., Simonsohn, U., Wagenmakers, E.-J., Ware, J. J., & Ioannidis, J. P. A. (2017). A manifesto for reproducible science. *Nature Human Behaviour*, *1*(1), 0021. https://doi.org/10.1038/s41562-016-0021

NCD Risk Factor Collaboration. (2017). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: A pooled analysis of 2416 population-based measurement studies in 128·9 million children, adolescents, and adults. *The Lancet*, 2627–2642.

Niessner, C., Hanssen-Doose, A., Eberhardt, T., Oriwol, D., Woll, A. Worth, A., & Bös, K. (2020). Motorische Leistungsfähigkeit. In C. Breuer, C. Josten, & W. Schmidt (Eds.), *Vierter Deutscher Kinder- und Jugendsportbericht: Gesundheit, Leistung und Gesellschaft: Vol. 4 (2020)* (1. Auflage, pp. 51–63). Hofmann-Verlag.

Niessner, C., Utesch, T., Oriwol, D., Hanssen-Doose, A., Schmidt, S. C. E., Woll, A., Bös, K., & Worth, A. (2020). Representative Percentile Curves of Physical Fitness From Early Childhood to Early Adulthood: The MoMo Study. *Frontiers in Public Health, 8,* 458. https://doi.org/10.3389/fpubh.2020.00458

Nigg, C., Oriwol, D., Wunsch, K., Burchartz, A., Kolb, S., Worth, A., Woll, A., & Niessner, C. (2021). Population density predicts youth's physical activity changes during Covid-19 – Results from the MoMo study. *Health & Place*, *70*, 102619. https://doi.org/10.1016/j.healthplace.2021.102619

Nigg, C., Weber, C., Schipperijn, J., Reichert, M., Oriwol, D., Worth, A., Woll, A., & Niessner, C. (2022). Urban-Rural Differences in Children's and Adolescent's Physical Activity and Screen-Time Trends Across 15 Years. *Health Education & Behavior : The Official Publication of the Society for Public Health Education*, 10901981221090153. https://doi.org/10.1177/10901981221090153

OECD. (2019). *Health in the 21st Century: Putting Data to Work for Stronger Health Systems*. OECD Publishing. https://doi.org/10.1787/e3b23f8e-en

Olds, T., & Dollman, J. (2004). Are Changes in Distance-Run Performance of Australian Children between 1985 and 1997 Explained by Changes in Fatness? *Pediatric Exercise Science*, *16*(3), 201–209. https://doi.org/10.1123/pes.16.3.201

Olds, T., Maher, C., Zumin, S., Péneau, S., Lioret, S., Castetbon, K., Bellisle, De Wilde, J., Hohepa, M., Maddison, R., Lissner, L., Sjöberg, A., Zimmermann, M., Aeberli, I., Ogden, C., Flegal, K., & Summerbell, C. (2011). Evidence that the prevalence of childhood overweight is plateauing: Data from nine countries. *International Journal of Pediatric Obesity*, *6*(5–6), 342–360. https://doi.org/10.3109/17477166.2011.605895

Olds, T. S., Ridley, K., & Tomkinson, G. R. (2007). Declines in Aerobic Fitness: Are They Only Due to Increasing Fatness? In G. R. Tomkinson & T. S. Olds (Eds.), *Medicine and Sport Science* (pp. 226–240). KARGER. https://doi.org/10.1159/000101394

Ortega, F. B., Leskošek, B., Blagus, R., Gil-Cosano, J. J., Mäestu, J., Tomkinson, G. R., Ruiz, J. R., Mäestu, E., Starc, G., Milanovic, I., Tammelin, T. H., Sorić, M., Scheuer, C., Carraro, A., Kaj, M., Csányi, T., Sardinha, L. B., Lenoir, M., Emeljanovas, A., … Jurak, G. (2023). European fitness landscape for children and adolescents: Updated reference values, fitness maps and country rankings based on nearly 8 million test results from 34 countries gathered by the FitBack network. *British Journal of Sports Medicine*, *57*(5), 299–310. https://doi.org/10.1136/bjsports-2022-106176.

Ortega, F. B., Ruiz, J. R., Castillo, M. J., & Sjöström, M. (2008). Physical fitness in childhood and adolescence: A powerful marker of health. *International Journal of Obesity (2005), 32*(1), 1–11. https://doi.org/10.1038/sj.ijo.0803774

Ortega, F. B., Ruiz, J. R., Hurtig-Wennlöf, A., Vicente-Rodríguez, G., Rizzo, N. S., Castillo, M. J., & Sjöström, M. (2010). Cardiovascular fitness modifies the associations between physical activity and abdominal adiposity in children and adolescents: The European Youth Heart Study. *British Journal of Sports Medicine*, *44*(4), 256–262. https://doi.org/10.1136/bjsm.2008.046391

Palomäki, S., Heikinaro-Johansson, P., & Huotari, P. (2015). Cardiorespiratory performance and physical activity in normal weight and overweight Finnish adolescents from 2003 to 2010. *Journal of Sports Sciences*, *33*(6), 588–596. https://doi.org/10.1080/02640414.2014.951874

Pampel, H., & Elger, K. (2021). Publikation und Zitierung von digitalen Forschungsdaten. In M. Putnings, H. Neuroth, & J. Neumann (Eds.), *Praxishandbuch Forschungsdatenmanagement* (pp. 521–536). De Gruyter.

Pate, R. R. (1995). Physical Activity and Public Health: A Recommendation From the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA*, *273*(5), 402. https://doi.org/10.1001/jama.1995.03520290054029

Pate, R. R., Oria, M., & Pillsbury, L. (Eds.) (with National Academies Press (US)). (2012). *Fitness Measures and Health Outcomes in Youth*. https://doi.org/10.17226/13483

Pombo, A., Luz, C., Sá, C., Rodrigues, L. P., & Cordovil, R. (2021). Effects of the COVID-19 Lockdown on Portuguese Children's Motor Competence. *Children (Basel, Switzerland)*, *8*(3). https://doi.org/10.3390/children8030199

Prince, S. A., Dempsey, P. C., Reed, J. L., Rubin, L., Saunders, T. J., Ta, J., Tomkinson, G. R., Merucci, K., & Lang, J. J. (2024). The Effect of Sedentary Behaviour on Cardiorespiratory Fitness: A Systematic Review and Meta-Analysis. *Sports Medicine*, *54*(4), 997–1013. https://doi.org/10.1007/s40279-023-01986-y

Radulović, A., Jurak, G., Leskošek, B., Starc, G., & Blagus, R. (2022). Secular trends in physical fitness of Slovenian boys and girls aged 7 to 15 years from 1989 to 2019: A population-based study. *Scientific Reports*, *12*(1), 10495. https://doi.org/10.1038/s41598-022-14813-7

Rauner, A., Mess, F., & Woll, A. (2013). The relationship between physical activity, physical fitness and overweight in adolescents: A systematic review of studies published in or after 2000. *BMC Pediatrics*, *13*, 19. https://doi.org/10.1186/1471-2431-13-19

Ravens-Sieberer, U., Erhart, M., Devine, J., Gilbert, M., Reiss, F., Barkmann, C., Siegel, N. A., Simon, A. M., Hurrelmann, K., Schlack, R., Hölling, H., Wieler, L. H., & Kaman, A. (2022). Child and Adolescent Mental Health During the COVID-19 Pandemic: Results of the Three-Wave Longitudinal COPSY Study. *Journal of Adolescent Health*, *71*(5), 570–578. https://doi.org/10.1016/j.jadohealth.2022.06.022

Robinson, L. E., Stodden, D. F., Barnett, L. M., Lopes, V. P., Logan, S. W., Rodrigues, L. P., & D'Hondt, E. (2015). Motor Competence and its Effect on Positive Developmental

Trajectories of Health. *Sports Medicine*, *45*(9), 1273–1284. https://doi.org/10.1007/s40279-015-0351-6

Rodrigues, L. P., Leitão, R., & Lopes, V. P. (2013). Physical fitness predicts adiposity longitudinal changes over childhood and adolescence. *Journal of Science and Medicine in Sport*, *16*(2), 118–123. https://doi.org/10.1016/j.jsams.2012.06.008

Rossi, L., Behme, N., & Breuer, C. (2021). Physical Activity of Children and Adolescents during the COVID-19 Pandemic-A Scoping Review. *International Journal of Environmental Research and Public Health*, *18*(21). https://doi.org/10.3390/ijerph182111440

Roth, K., Ruf, K., Obinger, M., Mauer, S., Ahnert, J., Schneider, W., Graf, C., & Hebestreit, H. (2010). Is there a secular decline in motor skills in preschool children? *Scandinavian Journal of Medicine & Science in Sports*, *20*(4), 670–678. https://doi.org/10.1111/j.1600-0838.2009.00982.x

Ruiz, J. R., Castro-Piñero, J., Artero, E. G., Ortega, F. B., Sjöström, M., Suni, J., & Castillo, M. J. (2009). Predictive validity of health-related fitness in youth: A systematic review. *British Journal of Sports Medicine*, *43*(12), 909–923. https://doi.org/10.1136/bjsm.2008.056499

Rümpel, S. (2011). Der Lebenszyklus von Forschungsdaten. In S. Büttner, H.-C. Hobohm, & L. Müller (Eds.), *Handbuch Forschungsdatenmanagement*. BOCK+HERCHEN Verlag. https://doi.org/10.34678/OPUS4-208

Salathé, M., Bengtsson, L., Bodnar, T. J., Brewer, D. D., Brownstein, J. S., Buckee, C., Campbell, E. M., Cattuto, C., Khandelwal, S., Mabry, P. L., & Vespignani, A. (2012). Digital Epidemiology. *PLoS Computational Biology*, *8*(7), e1002616. https://doi.org/10.1371/journal.pcbi.1002616

Sandercock, G. R. H., & Cohen, D. D. (2019). Temporal trends in muscular fitness of English 10-year-olds 1998–2014: An allometric approach. *Journal of Science and Medicine in Sport*, *22*(2), 201–205. https://doi.org/10.1016/j.jsams.2018.07.020

Sandercock, G. R. H., Ogunleye, A., & Voss, C. (2015). Six-year changes in body mass index and cardiorespiratory fitness of English schoolchildren from an affluent area. *International Journal of Obesity*, *39*(10), 1504–1507. https://doi.org/10.1038/ijo.2015.105

Sardinha, L. B., Marques, A., Minderico, C., Palmeira, A., Martins, S., Santos, D. A., & Ekelund, U. (2016). Longitudinal Relationship between Cardiorespiratory Fitness and Academic Achievement. *Medicine and Science in Sports and Exercise*, *48*(5), 839–844. https://doi.org/10.1249/MSS.0000000000000830

Scheid, V. (2009). Motorische Entwicklung in der frühen Kindheit. In J. Baur, K. Bös, A. Conzelmann, & R. Singer (Eds.), *Handbuch Motorische Entwicklung* (2nd ed., pp. 281–300). Hofmann.

Scheuer, C., Herrmann, C., & Bund, A. (2019). Motor tests for primary school aged children: A systematic review. *Journal of Sports Sciences*, *37*(10), 1097–1112. https://doi.org/10.1080/02640414.2018.1544535

Schilling, J., Tolksdorf, K., Marquis, A., Faber, M., Pfoch, T., Buda, S., Haas, W., Schuler, E., Altmann, D., Grote, U., & Diercke, M. (2021). Die verschiedenen Phasen der COVID-19-Pandemie in Deutschland: Eine deskriptive Analyse von Januar 2020 bis Februar 2021. *Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz*, *64*(9), 1093–1106. https://doi.org/10.1007/s00103-021-03394-x

Schmidt, S. C. E., Anedda, B., Burchartz, A., Eichsteller, A., Kolb, S., Nigg, C., Niessner, C., Oriwol, D., Worth, A., & Woll, A. (2020). Physical activity and screen time of children and adolescents before and during the COVID-19 lockdown in Germany: A natural experiment. *Scientific Reports*, *10*(1), 21780. https://doi.org/10.1038/s41598-020-78438-4

Schmidt, S. C. E., Anedda, B., Burchartz, A., Oriwol, D., Kolb, S., Wäsche, H., Niessner, C., & Woll, A. (2020). The physical activity of children and adolescents in Germany 2003-2017: The MoMo-study. *PloS One*, *15*(7), 0236117. https://doi.org/10.1371/journal.pone.0236117

Schmidt, S. C. E., Burchartz, A., Kolb, S., Niessner, C., Oriwol, D., Hanssen-Doose, A., Worth, A., & Woll, A. (2021a). *Zur Situation der körperlich-sportlichen Aktivität von Kindern und Jugendlichen während der COVID-19 Pandemie in Deutschland: Die Motorik-Modul Studie (MoMo)*. Karlsruher Institut für Technologie (KIT). https://doi.org/10.5445/IR/1000133697/V2

Schmidt, S. C. E., Burchartz, A., Kolb, S., Niessner, C., Oriwol, D., Hanssen-Doose, A., Worth, A., & Woll, A. (2021b). *Zur Situation der körperlich-sportlichen Aktivität von Kindern und Jugendlichen während der COVID-19 Pandemie in Deutschland: Die Motorik-Modul Studie (MoMo)*. Karlsruher Institut für Technologie (KIT). https://doi.org/10.5445/IR/1000133697/V2

Schmidt, S. C. E., Burchartz, A., Kolb, S., Niessner, C., Oriwol, D., & Woll, A. (2021). Influence of socioeconomic variables on physical activity and screen time of children and adolescents during the COVID-19 lockdown in Germany: The MoMo study. *German Journal of Exercise and Sport Research*. https://doi.org/10.1007/s12662-021-00783-x

Schmidt, S. C. E., Henn, A., Albrecht, C., & Woll, A. (2017). Physical Activity of German Children and Adolescents 2003-2012: The MoMo-Study. *International Journal of Environmental Research and Public Health*, *14*(11). https://doi.org/10.3390/ijerph14111375

Sedlak, P., Pařízková, J., Daniš, R., Dvořáková, H., & Vignerová, J. (2015). Secular Changes of Adiposity and Motor Development in Czech Preschool Children: Lifestyle Changes in Fifty-Five Year Retrospective Study. *BioMed Research International*, *2015*, e823841. https://doi.org/10.1155/2015/823841

Smith, J. J., Eather, N., Morgan, P. J., Plotnikoff, R. C., Faigenbaum, A. D., & Lubans, D. R. (2014). The health benefits of muscular fitness for children and adolescents: A systematic review and meta-analysis. *Sports Medicine (Auckland, N.Z.)*, *44*(9), 1209–1223. https://doi.org/10.1007/s40279-014-0196-4

Smpokos, E. A., Linardakis, M., Papadaki, A., Lionis, C., & Kafatos, A. (2012). Secular trends in fitness, moderate-to-vigorous physical activity, and TV-viewing among first grade school children of Crete, Greece between 1992/93 and 2006/07. *Journal of Science and Medicine in Sport*, *15*(2), 129–135. https://doi.org/10.1016/j.jsams.2011.08.006

Spengler, S., Rabel, M., Kuritz, A. M., & Mess, F. (2017). Trends in Motor Performance of First Graders: A Comparison of Cohorts from 2006 to 2015. *Frontiers in Pediatrics*, *5*, 206. https://doi.org/10.3389/fped.2017.00206

Stiller, J., Würth, S., & Alfermann, D. (2004). Die Messung des physischen Selbstkonzepts (PSK). *Zeitschrift Für Differentielle Und Diagnostische Psychologie*, *25*(4), 239–257. https://doi.org/10.1024/0170-1789.25.4.239

Stodden, Goodway, J. D., Langendorfer, S. J., Roberton, M. A., Rudisill, M. E., Garcia, C., & Garcia, L. E. (2008). A Developmental Perspective on the Role of Motor Skill Competence in Physical Activity: An Emergent Relationship. *Quest*, *60*(2), 290–306. https://doi.org/10.1080/00336297.2008.10483582

Stojan, R., Geukes, K., Piesch, L., Jetzke, M., Zinner, J., Büsch, D., & Utesch, T. (2023). *Motor performance in children before, during and after COVID-19 pandemic and the role of socioeconomic background: A 10-year cohort study of 68,996 third grade children*. https://doi.org/10.31219/osf.io/6qxrm

Tambalis, K. D., Panagiotakos, D. B., Psarra, G., & Sidossis, L. S. (2011). Inverse but independent trends in obesity and fitness levels among Greek children: A time-series analysis from 1997 to 2007. *Obesity Facts*, *4*(2), 165–174. https://doi.org/10.1159/000327994

Teich, P., Fühner, T., Bähr, F., Puta, C., Granacher, U., & Kliegl, R. (2023). Covid Pandemic Effects on the Physical Fitness of Primary School Children: Results of the German EMOTIKON Project. *Sports Medicine - Open*, *9*(1), 77. https://doi.org/10.1186/s40798-023-00624-1

Thistlewaite, D. L., & Campbell, D. T. (2017). Regression-discontinuity analysis: An alternative to the ex-post facto experiment. *Observational Studies*, *3*, 119–128.

Thomas, B. H., Ciliska, D., Dobbins, M., & Micucci, S. (2004). A Process for Systematically Reviewing the Literature: Providing the Research Evidence for Public Health Nursing Interventions. *Worldviews on Evidence-Based Nursing*, *1*(3), 176–184. https://doi.org/10.1111/j.1524-475X.2004.04006.x

Tittlbach, S., Kolb, H., Woll, A., & Bös, K. (2005). Karlsruher gesundheitsorientierter Koordinationstest (KGKT). *B&G Bewegungstherapie und Gesundheitssport*, *21*(06), 253–258. https://doi.org/10.1055/s-2005-918173

Tomkinson, G. R. (2007). Global changes in anaerobic fitness test performance of children and adolescents (1958-2003). *Scandinavian Journal of Medicine & Science in Sports*, *17*(5), 497–507. https://doi.org/10.1111/j.1600-0838.2006.00569.x

Tomkinson, G. R., Carver, K. D., Atkinson, F., Daniell, N. D., Lewis, L. K., Fitzgerald, J. S., Lang, J. J., & Ortega, F. B. (2018). European normative values for physical fitness in children and adolescents aged 9–17 years: Results from 2 779 165 Eurofit performances representing 30 countries. *British Journal of Sports Medicine*, *52*(22), 1445–1456. https://doi.org/10.1136/bjsports-2017-098253

Tomkinson, G. R., Kaster, T., Dooley, F. L., Fitzgerald, J. S., Annandale, M., Ferrar, K., Lang, J. J., & Smith, J. J. (2021). Temporal Trends in the Standing Broad Jump Performance of 10,940,801 Children and Adolescents Between 1960 and 2017. *Sports Medicine (Auckland, N.Z.)*, *51*(3), 531–548. https://doi.org/10.1007/s40279-020-01394-6

Tomkinson, G. R., Lang, J. J., & Tremblay, M. S. (2019). Temporal trends in the cardiorespiratory fitness of children and adolescents representing 19 high-income and upper middle-income countries between 1981 and 2014. *British Journal of Sports Medicine*, *53*(8), 478–486. https://doi.org/10.1136/bjsports-2017-097982

Tomkinson, G. R., & Olds, T. S. (Eds.). (2007a). *Pediatric Fitness: Secular Trends and Geographics Variability*. Karger.

Tomkinson, G. R., & Olds, T. S. (2007b). *Secular Changes in Pediatric Aerobic Fitness Test Performance: The Global Picture*. 46–66. https://doi.org/10.1159/000101075

Tomkinson, G. R., & Olds, T. S. (2007c). Secular changes in pediatric aerobic fitness test performance: The global picture. *Medicine and Sport Science*, *50*, 46–66. https://doi.org/10.1159/000101075

Tremblay, M. S., LeBlanc, A. G., Kho, M. E., Saunders, T. J., Larouche, R., Colley, R. C., Goldfield, G., & Gorber, S. (2011). Systematic review of sedentary behaviour and health indicators in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *8*(1), 98. https://doi.org/10.1186/1479-5868-8-98

Tremblay, M. S., Shields, M., Laviolette, M., Craig, C. L., Janssen, I., & Connor Gorber, S. (2010). Fitness of Canadian children and youth: Results from the 2007-2009 Canadian Health Measures Survey. *Health Reports*, *21*(1), 7–20.

UNESCO (Ed.). (2021). *UNESCO Recommendation on Open Science*. UNESCO. https://doi.org/10.54677/MNMH8546

Utesch, T., Bardid, F., Büsch, D., & Strauss, B. (2019). The Relationship Between Motor Competence and Physical Fitness from Early Childhood to Early Adulthood: A Meta-Analysis. *Sports Medicine*, *49*(4), 541–551. https://doi.org/10.1007/s40279-019-01068-y

Utesch, T., Dreiskämper, D., & Geukes, K. (2017). Open Science in der Sportwissenschaft?: Ein Wegweiser zur Präregistrierung von Forschungsvorhaben und zu offenem Material, offenen Daten und offenem Code. *Zeitschrift für Sportpsychologie*, *24*(3), 92–99. https://doi.org/10.1026/1612-5010/a000205

Utesch, T., Dreiskämper, D., Naul, R., & Geukes, K. (2018). Understanding physical (in-) activity, overweight, and obesity in childhood: Effects of congruence between physical self-concept and motor competence. *Scientific Reports*, *8*(1), 5908. https://doi.org/10.1038/s41598-018-24139-y

Utesch, T., Dreiskämper, D., Strauss, B., & Naul, R. (2018). The development of the physical fitness construct across childhood. *Scandinavian Journal of Medicine & Science in Sports*, *28*(1), 212–219. https://doi.org/10.1111/sms.12889

Utesch, Till, & Bardid, F. (2019). Motor Competence. In *Dictionary of sport psychology: Sport, exercise, and performing arts* (p. 186). Academic press.

van Bon-Martens, M., Van Oers, H., Verschuuren, M., & Zwakhals, L. (2019). Population Health Reporting. In M. Verschuuren & H. Van Oers (Eds.), *Population Health Monitoring: Climbing the Information Pyramid* (pp. 1–9).

Venckunas, T., Emeljanovas, A., Mieziene, B., & Volbekiene, V. (2017). Secular trends in physical fitness and body size in Lithuanian children and adolescents between 1992 and 2012. *J Epidemiol Community Health*, *71*(2), 181–187. https://doi.org/10.1136/jech-2016-207307

Verschuuren, M., & Van Oers, H. (2019). Introduction. In M. Verschuuren & H. Van Oers (Eds.), *Population Health Monitoring: Climbing the Information Pyramid* (pp. 1–9).

Verschuuren, M., & Van Oers, H. (2020). Population health monitoring: An essential public health field in motion. *Bundesgesundheitsblatt - Gesundheitsforschung - Gesundheitsschutz*, *63*(9), 1134–1142. https://doi.org/10.1007/s00103-020-03205-9

Wahl-Alexander, Z., & Camic, C. L. (2021). Impact of COVID-19 on School-Aged Male and Female Health-Related Fitness Markers. *Pediatric Exercise Science*, *33*(2), 61–64. https://doi.org/10.1123/pes.2020-0208

Wang, R. Y., & Strong, D. M. (1996). Beyond Accuracy: What Data Quality Means to Data Consumers. *Journal of Management Information Systems*, *12*(4), 5–33. https://doi.org/10.1080/07421222.1996.11518099

Wang, Y., & Lobstein, T. (2006). Worldwide trends in childhood overweight and obesity. *International Journal of Pediatric Obesity: IJPO: An Official Journal of the International Association for the Study of Obesity*, *1*(1), 11–25. https://doi.org/10.1080/17477160600586747

Wessely, S., Ferrari, N., Friesen, D., Grauduszus, M., Klaudius, M., & Joisten, C. (2022). Changes in Motor Performance and BMI of Primary School Children over Time-Influence of the COVID-19 Confinement and Social Burden. *International Journal of Environmental Research and Public Health*, *19*(8). https://doi.org/10.3390/ijerph19084565

Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., Da Silva Santos, L. B., Bourne, P. E., Bouwman, J., Brookes, A. J., Clark, T., Crosas, M., Dillo, I., Dumon, O., Edmunds, S., Evelo, C. T., Finkers, R.,Mons, B. (2016). The FAIR Guiding Principles for scientific data management and stewardship. *Scientific Data*, *3*, 160018. https://doi.org/10.1038/sdata.2016.18

Willimczik, K., & Conzelmann, A. (1999). Motorische Entwicklung in der Lebensspanne. Kernannahmen und Leitorientierungen. *Psychologie Und Sport*, *6*(2), 60–70.

Woll, A., Klos, L., Burchartz, A., Hanssen-Doose, A., Niessner, C., Oriwol, D., Schmidt, S. C. E., Bös, K., & Worth, A. (2021). Cohort Profile Update: The Motorik-Modul (MoMo) Longitudinal Study-physical fitness and physical activity as determinants of health development in German children and adolescents. *International Journal of Epidemiology*. https://doi.org/10.1093/ije/dyaa281

Woll, A., Oriwol, D., Anedda, B., Burchartz, A., Hanssen-Doose, A., Kopp, M., Niessner, C., Schmidt, S. C. E., Bös, K., & Worth, A. (2019). Körperliche Aktivität, motorische Leistungsfähigkeit und Gesundheit in Deutschland: Ergebnisse aus der Motorik-Modul-Längsschnittstudie (MoMo). *KIT Scientific Working Papers*, *121*. https://doi.org/10.5445/IR/1000095369

World Health Organization (Ed.). (2022). *Global status report on physical activity 2022*. World Health Organization.

Worth, A., Niessner, C., & Utesch, T. (2022). *Sportmotorische Testsverfahren zur Diagnostik von motorischer Leistungsfähigkeit* (pp. 275–292). Hogrefe.

Wunsch, K., Kienberger, K., & Niessner, C. (2022). Changes in Physical Activity Patterns Due to the Covid-19 Pandemic: A Systematic Review and Meta-Analysis. *International Journal of Environmental Research and Public Health*, *19*(4). https://doi.org/10.3390/ijerph19042250

Appendix A

Supplementary Material Chapter 2

Table S1. EPHPP Assessment for included studies

		Ao et al. [1]	*Bai et al. [2]*	*Boddy et al. [3]*	*Cohen et al. [4]*	*Costa et al. [5]*	*Dos Santos et al. [6]*	*Dyrstad et al. [7]*	*Ekblom et al. [8]*	*Fraser et al. [9]*	*Hardy et al. [10]*	*Moliner-Urdiales et al. [11]*	*Moraes Ferrari et al. [12]*
A	*Selection Bias*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*

Appendix A

Q1	*Are the individuals selected to participate in the study likely to be representative of the target population? 1 very likely 2 some what likely 3 not likely 4 can't tell*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*2*	*2*

Q2	*What percentage of selected individuals agreed to participate? 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 not applicable 5 can't tell*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*
B	*Study Design*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*

Appendix A

	Indicate the study design 1 randomized controlled trial 2 controlled clinical trial 3 cohort analytic (two group pre and post) 4 case-control 5 cohort (one group pre and post (before and after)) 6 interrupted time series 7 other specify 8 can't tell	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*

C	Con-found ers	mod er-ate	mod er-ate	stro ng	stro ng	stro ng	stro ng	mod er-ate	mod er-ate	stro ng	stro ng	mod er-ate	stro ng
Q 1	Were there im-porta nt differ-ences be-tween group s prior to the inter-ven-tion? 1 yes 2 no 3 can't tell	1	1	1	1	1	1	1	1	1	1	1	2

Q2	*If yes, indicate the percentage for relevant confounders that were controlled (either in the design (e.g. stratification, matching) or analysis)? 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 can't tell*	*2*	*2*	*1*	*1*	*1*	*1*	*2*	*2*	*1*	*1*	*2*	*2*
D	*Blinding*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*

Q 1	*Was (were) the out-come asses-sor(s) aware of the inter-ven-tion or expo-sure status of par-tici-pants? 1 yes 2 no 3 can't tell*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Q 2	*Were the study par-tici-pants aware of the re-search ques-tion? 1 yes 2 no 3 can't tell*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*

Appendix A

E	*Data collection methods*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*
Q 1	*Were data collection tools shown to be valid? 1 yes 2 no 3 can't tell*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Q 2	*Were data collection tools shown to be reliable? 1 yes 2 no 3 can't tell*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
F	*Withdrawals and dropouts*	*Weak*	*weak*	*weak*	*weak*	*weak*	*weak*	*strong*	*weak*	*weak*	*weak*	*weak*	*weak*

Q1	*Were withdrawals and dropouts reported in terms of numbers and/or reasons per group? 1 yes 2 no 3 can't tell 4 not applicable (i.e. one time surveys or interviews)*	*2*	*2*	*2*	*2*	*2*	*2*	*1*	*1*	*2*	*2*	*2*	*2*

Q2	*Indicate the percentage of participants completing the study. (if the percentage differs by groups, record the lowest). 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 can't tell 5 not applicable (i.e. retrospective case-control)*	*4*	*4*	*4*	*4*	*4*	*4*	*1*	*3*	*4*	*4*	*4*	*4*

	GLOBAL RATING	moderate	moderate	moderate	moderate	moderate	moderate	strong	moderate	moderate	moderate	moderate	moderate
		Morales-Demori et al. [13]	*Müllerova et al. [14]*	*Palomäki et al. [15]*	*Roth et al. [16]*	*Sandercock et al. [17]*	*Sandercock et al. [18]*	*Sedlak et al. [19]*	*Smpokos et al. [20]*	*Spengler et al. [21]*	*Tambalis et al. [22]*	*Tremblay et al. [23]*	*Venckunas et al. [24]*
A	*Selection Bias*	*moderate*	*weak*	*moderate*	*moderate*	*moderate*	*strong*	*moderate*	*moderate*	*moderate*	*strong*	*moderate*	*moderate*

Appendix A

Q 1	*Are the individuals selected to participate in the study likely to be representative of the target population? 1 very likely 2 some what likely 3 not likely 4 can't tell*	*2*	*1*	*1*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*1*

Q2	*What percentage of selected individuals agreed to participate? 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 not applicable 5 can't tell*	*5*	*3*	*5*	*5*	*5*	*1*	*5*	*5*	*5*	*1*	*5*	*5*
B	*Study Design*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*

	Indicate the study design 1 randomized controlled trial 2 controlled clinical trial 3 cohort analytic (two group pre and post) 4 case-control 5 cohort (one group pre and post (before and after)) 6 interrupted time series 7 other	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*	*6*

C	*Con-founders*	*strong*	*strong*	*strong*	*moderate*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*
Q1	*Were there important differences between groups prior to the intervention? 1 yes 2 no 3 can't tell*	*2*	*3*	*1*	*1*	*2*	*2*	*2*	*2*	*1*	*1*	*2*	*2*

Q2	*If yes, indicate the percentage fo relevant confounders that were controlled (either in the design (e.g. stratification, matching) or analysis)? 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 can't tell*	*1*	*1*	*1*	*2*	*2*	*1*	*2*	*1*	*1*	*1*	*2*	*1*

D	*Blind-ing*	*mo de-rate*	*mod er-ate*	*mo de-rate*	*mo de-rate*	*mod er-ate*	*mod er-ate*	*mo de-rate*	*mo de-rate*	*mo de-rate*	*mo de-rate*	*mo de-rate*	*mod er-ate*
Q 1	*Was (were) the out-come asses-sor(s) aware of the inter-ven-tion or expo-sure status of par-tici-pants? 1 yes 2 no 3 can't tell*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*
Q 2	*Were the study par-tici-pants aware of the re-search ques-tion? 1 yes 2 no 3 can't tell*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*3*	*1*

Appendix A

E	*Data collection methods*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*	*strong*
Q1	*Were data collection tools shown to be valid? 1 yes 2 no 3 can't tell*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
Q2	*Were data collection tools shown to be reliable? 1 yes 2 no 3 can't tell*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*	*1*
F	*Withdrawals and drop-outs*	*weak*	*weak*	*strong*	*weak*	*weak*	*weak*	*weak*	*weak*	*weak*	*weak*	*weak*	*weak*

Q 1	*Were with-drawals and drop-outs re-port-ed in terms of num-bers and/or rea-sons per group? 1 yes 2 no 3 can't tell 4 not appli-cable (i.e. one time sur-veys or inter-views)*	*2*	*2*	*1*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*	*2*

Q2	*Indicate the percentage of participants completing the study. (if the percentage differs by groups, record the lowest). 1 80-100% agreement 2 60-79% agreement 3 less than 60% agreement 4 can't tell 5 not applicable (i.e. retrospective case-control)*	*4*	*4*	*1*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*	*4*

	GLOBAL RATING	*moderate*	*weak*	*strong*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*	*moderate*

Table S2. Review Protocol

Title	*Secular Trends in Physical Fitness of Children and Adolescents: Review of Large-scale Epidemiological Studies Published after 2006*
Authors	*Tanja Eberhardt[1], Claudia Niessner[1], Doris Oriwol[1], Lydia Buchal[1], Annette Worth[2] und Klaus Bös[1]* *[1] Institute of Sports and Sports Science, Karlsruhe Institute of Technology, Karlsruhe, Germany* *[2] Institute of Physical Education and Sports, University of Education Karlsruhe, Karlsruhe, Germany*
Reviewers	*Tanja Eberhardt, Claudia Niessner*
Support / Supervisors	*Klaus Bös*
1. *Background*	
Monitoring of physical fitness (PF) in youth is important, because PF is known as one of the most relevant resource for health (Hamer et al., 2020; Ortega et al., 2008; Ruiz et al., 2006; Dwyer et al., 2009) and is regarded as one of the foundations of an active lifestyle (Stodden et al., 2008). *Childhood is a critical period for the development of motor PF as it lays the foundation for later PF. Young children acquire a wide range of locomotor and object control skills that enable them to learn adaptive, skilled actions and to adjust them flexibly in different contexts. PF is the base on which children can build more specific motor skills or develop movement patterns (Clark & Humphrey, 2002; Cliff et al., 2016).* *The development of MP either encourages or discourages an individual to engage in physical activity through limiting one's opportunities (Cliff et al., 2016; Jaakola et al., 2016; Lubans et al., 2010; Larsen et al., 2015).* *Various definitions of the term PF exist. In Germany, the most commonly used definition was published by Bös (1987). According to this definition, five main dimensions of PF can be distinguished: endurance, strength, speed, and coordination, with flexibility as an additional passive dimension (Lämmle et al., 2010). This definition is based on the concept of physical fitness by Caspersen, Powell & Christenson (1985) and is the basic of this analyses.* *In many parts of life, systematic monitoring is used to document changes in society and to describe their course over a certain period of time. Considering the high impact of PF on health in childhood and adolescence, it is crucial to examine how PF has changed over time in children and adolescents. Systematic monitoring of PF is thus needed to assess, and design interventions and programs aiming to maintain or increase PF (Tomkinson et al., 2007; Greier et al, 2019; Hanssen-Doose et al., 2020).*	
2. *Objectives*	
The objective of this review is to summarize the evidence regarding secular trends in physical fitness of children and adolescents in large- scale epidemiological studies published after 2006	

3. *Inclusion criteria*	
Population / participants	*Participants between the ages of 4 to 18 years*
Interest / exposure	*No intervention*
Comparison group	*Comparison(s) with former measurement point(s)*
Outcome of interest	*Statements of trends in the different dimensions of physical fitness (endurance, strength, speed, flexibility and coordination)*
Study design	*Cohort studies with at least two different measurement points*
Other criteria	*Single study articles published in peer-reviewed journals (full-texts)* *English language*
Exclusion criteria	• *Study populations characterized by a physical disease or conducted in a clinical setting, such as diabetes or preterm birth. Additionally, studies among participants with a competitive athletic background* • *Study population N <100* • *Studies analysing relations, effects or influences of a specific variable such as socio-demographic status* • *Articles published in any other language than English*
4. *Search Methods*	
Electronic Databases	*The following databases will be searched: PubMed*
5. *Methods of the Review*	
Details of methods	*All identified articles are exported to a reference manager program. In a first step, duplicates will be removed. In the second step, articles will be screened based on title and abstract, and in the third step, based on full-texts. The whole screening process will be conducted by two reviewers independently.* *Two main reviewers (Tanja Eberhardt, Lydia Buchal) will review the studies. Studies will be included based on agreement of two reviewers, a third reviewer will be contacted (Claudia Niessner) for any disagreements.* *The same approach will be taken for the study quality assessment.*
Quality assessment	*EPHPP Assessment tool*

Data extraction	*Data will be extracted and summarized in a Table, including:* • *Authors and year* • *Country* • *Period* • *Measurements* • *Age* • *Sample size* • *Dimension of physical fitness tested* • *Test Items*
Data synthesis	• *Categorization into three directions of trends Increase- Stagnation- Decrease*

Full Search Strategy

Search: ((children OR adolescent* OR youth OR child OR Kinder OR Jugendliche) AND (cohort stud* OR Kohortenstudie* OR survey OR longitudinal OR trend* OR secular OR follow-up)) AND ("Motor performance" OR "körperlicheLeistungsfähigkeit" OR "physical fitness" OR fitness) Filters: English, from 2006 - 2020

((((((((((("child"[MeSH Terms] OR "child"[All Fields]) OR "children"[All Fields]) OR "child s"[All Fields]) OR "children s"[All Fields]) OR "childrens"[All Fields]) OR "childs"[All Fields]) OR "adolescent*"[All Fields]) OR (((("adolescent"[MeSH Terms] OR "adolescent"[All Fields]) OR "youth"[All Fields]) OR "youths"[All Fields]) OR "youth s"[All Fields])) OR (((((("child"[MeSH Terms] OR "child"[All Fields]) OR "children"[All Fields]) OR "child s"[All Fields]) OR "children s"[All Fields]) OR "childrens"[All Fields]) OR "childs"[All Fields])) OR "Kinder"[All Fields]) OR "Jugendliche"[All Fields]) AND ((((((((((((("cohort studies"[MeSH Terms] OR ("cohort"[All Fields] AND "studies"[All Fields])) OR "cohort studies"[All Fields]) OR "cohort"[All Fields]) OR "cohort s"[All Fields]) OR "cohorte"[All Fields]) OR "cohorts"[All Fields]) AND "stud*"[All Fields]) OR "kohortenstudie*"[All Fields]) OR ((((((("survey s"[All Fields] OR "surveyed"[All Fields]) OR "surveying"[All Fields]) OR "surveys and questionnaires"[MeSH Terms]) OR ("surveys"[All Fields] AND "questionnaires"[All Fields])) OR "surveys and questionnaires"[All Fields]) OR "survey"[All Fields]) OR "surveys"[All Fields])) OR ("longitudinal"[All Fields] OR "longitudinally"[All Fields])) OR "trend*"[All Fields]) OR ((((((("secular"[All Fields] OR "secularism"[MeSH Terms]) OR "secularism"[All Fields]) OR "secularity"[All Fields]) OR "secularization"[All Fields]) OR "secularized"[All Fields]) OR "secularizing"[All Fields]) OR "seculars"[All Fields])) OR "follow-up"[All Fields])) AND ((("Motor performance"[All Fields] OR ("motorische"[All Fields] AND "leistungsfahigkeit"[All Fields])) OR "physical fitness"[All Fields]) OR ("fitness"[All Fields] OR "fitnesses"[All Fields]))

Translations

children: "child"[MeSH Terms] OR "child"[All Fields] OR "children"[All Fields] OR "child's"[All Fields] OR "children's"[All Fields] OR "childrens"[All Fields] OR "childs"[All Fields]

youth: "adolescent"[MeSH Terms] OR "adolescent"[All Fields] OR "youth"[All Fields] OR "youths"[All Fields] OR "youth's"[All Fields]

child: "child"[MeSH Terms] OR "child"[All Fields] OR "children"[All Fields] OR "child's"[All Fields] OR "children's"[All Fields] OR "childrens"[All Fields] OR "childs"[All Fields] cohort: "cohort studies"[MeSH Terms] OR ("cohort"[All Fields] AND "studies"[All Fields]) OR "cohort studies"[All Fields] OR "cohort"[All Fields] OR "cohort's"[All Fields] OR "cohorte"[All Fields] OR "cohorts"[All Fields]

survey: "survey's"[All Fields] OR "surveyed"[All Fields] OR "surveying"[All Fields] OR "surveys and questionnaires"[MeSH Terms] OR ("surveys"[All Fields] AND "questionnaires"[All Fields]) OR "surveys and questionnaires"[All Fields] OR "survey"[All Fields] OR "surveys"[All Fields]

longitudinal: "longitudinal"[All Fields] OR "longitudinally"[All Fields]

secular: "secular"[All Fields] OR "secularism"[MeSH Terms] OR "secularism"[All Fields] OR "secularity"[All Fields] OR "secularization"[All Fields] OR "secularized"[All Fields] OR "secularizing"[All Fields] OR "seculars"[All Fields]

fitness: "fitness"[All Fields] OR "fitnesses"[All Fields]

Appendix B

Appendix Chapter 4

Table A1. Mean values for each test item and cohort overall and separately for boys and girls

Test Item	*Cohort*	*Mean Value (95% CI)*		
		Male	*Female*	*Overall*
20 m	*2012*	*4.03 (3.94–4.11)*	*4.33 (4.19–4.48)*	*4.16 (4.08–4.24)*
	2013	*4.15 (4.07–4.24)*	*4.35 (4.22–4.47)*	*4.23 (4.15–4.30)*
	2014	*3.91 (3.83–4.00)*	*3.94 (3.85–4.02)*	*3.92 (3.86–3.98)*
	2015	*3.83 (3.71–3.96)*	*3.89 (3.75–4.04)*	*3.86 (3.77–4.00)*
	2016	*3.99 (3.88–4.10)*	*4.10 (3.94–4.26)*	*4.02 (3.93–4.12)*
	2017	*3.85 (3.75–3.94)*	*4.00 (3.90–4.09)*	*3.91 (3.85–3.98)*
	2018	*4.34 (4.26–4.41)*	*4.54 (4.43–4.65)*	*4.42 (4.36–4.49)*
	2019	*4.43 (4.30–4.57)*	*4.62 (4.47–4.76)*	*4.52 (4.42–4.62)*
	2020	*4.34 (4.21–4.47)*	*4.41 (4.30–4.52)*	*4.38 (4.29–4.46)*
	2021	*4.38 (4.20–4.55)*	*4.43 (4.22–4.63)*	*4.40 (4.27–4.53)*
BalBw	*2012*	*39.74 (37.60–41.87)*	*36.86 (33.85–39.88)*	*38.49 (36.71–40.26)*
	2013	*39.80 (37.80–41.81)*	*38.64 (36.10–41.18)*	*39.35 (37.80–40.90)*
	2014	*36.39 (33.96–38.82)*	*39.14 (36.56–41.72)*	*37.61 (35.85–39.37)*
	2015	*35.23 (32.16–38.30)*	*35.61 (31.99–39.22)*	*35.39 (33.11–37.67)*
	2016	*39.27 (37.38–41.16)*	*39.91 (37.78–42.04)*	*39.50 (38.09–40.91)*
	2017	*35.73 (33.68–37.78)*	*36.79 (34.33–39.24)*	*36.18 (34.63–37.73)*
	2018	*36.61 (34.71–38.51)*	*36.98 (35.15–38.81)*	*36.77 (35.45–38.09)*
	2019	*33.43 (31.04–35.82)*	*36.41 (34.42–38.39)*	*34.87 (33.30–36.43)*
	2020	*35.33 (32.42–38.24)*	*38.56 (36.08–41.05)*	*37.11 (35.23–39.00)*
	2021	*37.90 (35.88–39.93)*	*40.72 (38.51–42.94)*	*39.34 (37.84–40.84)*
JumpSw	*2012*	*30.48 (28.64–32.32)*	*29.90 (27.50–32.30)*	*30.23 (28.78–31.68)*
	2013	*31.62 (29.37–33.86)*	*31.45 (28.96–33.94)*	*31.55 (29.90–33.20)*
	2014	*31.35 (29.41–33.29)*	*34.01 (32.04–35.98)*	*32.53 (31.14–33.92)*
	2015	*32.78 (30.20–35.37)*	*32.09 (28.49–35.69)*	*32.49 (30.42–34.56)*
	2016	*33.95 (32.14–35.76)*	*31.80 (29.77–33.84)*	*33.18 (31.81–34.55)*
	2017	*29.84 (27.98–31.71)*	*29.67 (27.64–31.70)*	*29.77 (28.42–31.13)*
	2018	*35.29 (33.59–36.98)*	*33.17 (31.23–35.10)*	*34.38 (33.11–35.53)*
	2019	*31.33 (29.70–32.97)*	*31.77 (29.90–33.64)*	*31.54 (30.32–32.76)*
	2020	*36.68 (34.03–39.34)*	*35.83 (33.53–38.14)*	*36.23 (34.51–37.94)*
	2021	*33.77 (31.86–35.68)*	*32.56 (30.59–34.54)*	*33.15 (31.79–34.51)*

St&R	*2012*	*4.48 (3.34–5.62)*	*5.54 (4.32–6.76)*	*4.94 (4.11–5.77)*
	2013	*4.84 (3.49–6.20)*	*6.40 (4.85–7.95)*	*5.45 (4.43–6.47)*
	2014	*2.70 (1.05–4.35)*	*5.20 (3.39–7.02)*	*3.81 (2.58–5.03)*
	2015	*−0.02 (−2.73–2.69)*	*4.94 (2.41–7.47)*	*2.01 (0.06–3.96)*
	2016	*−0.21 (−1.89–1.48)*	*2.97 (0.82–5.12)*	*0.90 (−0.44–2.24)*
	2017	*−1.60 (−3.59–0.39)*	*2.09 (−0.22–4.40)*	*0.07 (−1.46–1.60)*
	2018	*−2.43 (−3.84–−1.02)*	*1.74 (−0.16–3.63)*	*−0.62 (−1.81–0.57)*
	2019	*−1.13 (−2.82–0.56)*	*2.17 (0.55–3.79)*	*0.47 (−0.73–1.66)*
	2020	*2.57 (0.17–4.97)*	*3.82 (2.08–5.57)*	*3.25 (1.82–4.68)*
	2021	*−0.99 (−3.06–1.08)*	*3.54 (2.04–5.04)*	*1.32 (−0.01–2.64)*
PU	*2012*	*13.61 (12.63–14.60)*	*13.14 (12.13–14.15)*	*13.41 (12.71–14.10)*
	2013	*13.18 (12.39–13.98)*	*12.54 (11.55–13.53)*	*12.93 (12.32–13.54)*
	2014	*14.96 (13.37–16.56)*	*16.09 (14.56–17.63)*	*15.46 (14.36–16.57)*
	2015	*13.85 (12.68–15.01)*	*13.71 (12.21–15.21)*	*13.79 (12.89–14.69)*
	2016	*14.19 (13.43–14.94)*	*12.85 (11.92–13.77)*	*13.71 (13.11–14.30)*
	2017	*13.47 12.50–14.45)*	*13.14 (11.93–14.34)*	*13.33 (12.58–14.07)*
	2018	*14.94 (14.40–15.48)*	*14.67 (14.07–15.27)*	*14.82(14.42–15.22)*
	2019	*17.65 (16.93–18.37)*	*17.45 (16.73–18.17)*	*17.55 (17.05–18.06)*
	2020	*15.98 (14.75–17.20)*	*17.49 (16.48–18.50)*	*16.78 (16.00–17.57)*
	2021	*14.88 (13.77–16.00)*	*15.96 (14.99–16.93)*	*15.44 (14.71–16.17)*
SU	*2012*	*15.88 (14.75–17.00)*	*14.70 (13.34–16.06)*	*15.36 (14.50–16.23)*
	2013	*19.32 (17.76–20.87)*	*16.84 (15.41–18.27)*	*18.36 (17.24–19.47)*
	2014	*16.87 (15.29–18.44)*	*17.90 (16.06–19.75)*	*17.32 (16.14–18.50)*
	2015	*17.54 (15.41–19.67)*	*17.26 (14.73–19.78)*	*17.42 (15.84–19.01)*
	2016	*19.09 (17.60–20.57)*	*16.65 (14.61–18.68)*	*18.23 (17.03–19.43)*
	2017	*17.25 (16.01–18.49)*	*14.55 (13.29–15.81)*	*16.09 (15.18–17.01)*
	2018	*18.11 (16.79–19.43)*	*15.78 (14.19–17.36)*	*17.10 (16.08–18.12)*
	2019	*20.32 (18.76–21.88)*	*18.59 (17.22–19.97)*	*19.48 (18.44–20.52)*
	2020	*20.00 (18.08–21.92)*	*18.60 (17.18–20.01)*	*19.25 (18.09–20.41)*
	2021	*19.71 (18.02–21.40)*	*17.70 (16.03–19.37)*	*18.69 (17.51–19.87)*

SLJ	*2012*	*139.54 (134.95–144.13)*	*120.59 (114.53–126.65)*	*131.29 (127.21–135.37)*
	2013	*132.90 (127.89–137.92)*	*124.92 (118.14–131.71)*	*129.79 (125.74–133.84)*
	2014	*133.58 (128.50–138.67)*	*134.84 (128.92–140.76)*	*134.13 (130.34–137.92)*
	2015	*133.90 (129.10–138.70)*	*125.00 (116.76–133.24)*	*130.26 (125.85–134.66)*
	2016	*129.37 (124.65–134.09)*	*117.67 (110.92–124.42)*	*125.17 (121.20–129.15)*
	2017	*138.72 (133.39–144.05)*	*120.53 (115.73–125.32)*	*131.22 (127.15–135.29)*
	2018	*131.91 (129.87–136.94)*	*121.63 (116.18–127.07)*	*127.50 (123.73–131.27)*
	2019	*134.44 (129.30–139.59)*	*125.14 (119.90–130.37)*	*129.98 (126.27–133.70)*
	2020	*139.41 (133.13–145.70)*	*133.04 (127.39–138.70)*	*135.98 (131.80–140.15)*
	2021	*132.75 (126.53–138.97)*	*126.57 (121.29–131.86)*	*129.60 (125.56–133.65)*
6 min	*2012*	*1056.79 (1019.57–1094.01)*	*903.60 (859.31–947.90)*	*990.92 (959.09–1022.75)*
	2013	*1044.85 (1010.55–1079.14)*	*948.78 (907.96–989.61)*	*1007.82 (980.29–1035.35)*
	2014	*1016.37 (975.45–1057.28)*	*936.19 (893.23–979.15)*	*980.54 (950.28–1010.80)*
	2015	*996.31 (953.16–1039.46)*	*974.18 (936.37–1011.99)*	*987.06 (957.98–1016.14)*
	2016	*1026.43 (988.75–1064.10)*	*919.73 (876.69–962.76)*	*988.97 (958.83–1019.11)*
	2017	*1032.39 (996.43–1068.34)*	*950.41 (905.34–995.49)*	*997.01 (968.11–1025.91)*
	2018	*1022.42 (990.24–1054.60)*	*931.18 (900.59–961.77)*	*983.82 (959.87–1007.77)*
	2019	*1103.38 (1052.19–1154.57)*	*955.44 (920.26–990.62)*	*1031.84 (998.10–1065.57)*
	2020	*1045.39 (996.26–1094.52)*	*963.89 (918.40–1009.38)*	*1001.86 (968.03–1035.70)*
	2021	*1004.31 (956.22–1052.41)*	*939.65 (904.93–974.37)*	*969.65 (940.40–998.90)*

20-m Dash: 20 m; Balancing Backwards: BalBw; Jumping Sideways: JumpSw; Stand and Reach: St&R; Push-Ups: PU; Sit-Ups: SU; Standing Long Jump: SLJ; 6-min Run: 6 min

Table A2. Adjusted mean values of the ANCOVA in each test item - PreCOVID vs. COVID1

Test Item	*PreCOVID Mean Value (95% CI)*	*COVID1 Mean Value (95% CI)*	*Pairwise Comparisons Δ Mean Value (SD)*
20 m	*4.16 (4.13–4.19)*	*4.36 (4.27–4.46)*	*Δ +0.20 (0.05)* $p < 0.001$
BalBw	*37.26 (36.68–37.84)*	*37.04 (35.28–38.80)*	*Δ −0.22 (0.95)* $p = 0.813$
JumpSw	*31.95 (31.43–32.47)*	*36.27 (34.72–37.81)*	*Δ +4.32 (0.83)* $p < 0.001$
St&R	*2.09 (1.63–2.55)*	*2.98 (1.61–4.34)*	*Δ +0.88 (0.74)* $p = 0.230$
PU	*14.49 (14.23–14.76)*	*16.78 (15.98–17.58)*	*Δ +2.29 (0.43)* $p < 0.001$
SU	*17.45 (17.06–17.84)*	*19.40 (18.25–20.56)*	*Δ +1.95 (0.62)* $p = 0.002$
SLJ	*129.80 (128.43–131.14)*	*137.02 (132.99–141.06)*	*Δ +7.24 (2.17)* $p = 0.001$
6 min	*996.33 (986.26–1006.40)*	*1011.64 (981.75–1041.53)*	*Δ +15.31 (16.08)* $p = 0.341$

20-m Dash: 20 m; Balancing Backwards: BalBw; Jumping Sideways: JumpSw; Stand and Reach: St&R; Push-Ups: PU; Sit-Ups: SU; Standing Long Jump: SLJ; 6-min Run: 6 min

Table A3. Adjusted mean values of the ANCOVA in each test item – PreCOVID vs. COVID2

Test Item	*PreCOVID Mean Value (95% CI)*	*COVID2 Mean Value (95% CI)*	*Pairwise Comparisons Δ Mean Value (SD)*
20 m	*4.19 (4.13–4.19)*	*4.39 (4.29–4.49)*	*Δ +0.23 (0.05) p < 0.001*
BalBw	*37.26 (36.69–37.83)*	*39.29 (37.72–40.86)*	*Δ +2.03 (0.85) p = 0.017*
JumpSw	*31.95 (31.44–32.46)*	*33.19 (31.80–34.57)*	*Δ +1.24 (0.75) p = 0.100*
St&R	*2.09 (1.64–2.55)*	*1.10 (−0.15–2.34)*	*Δ −1.00 (0.68) p = 0.142*
PU	*14.49 (14.23–14.76)*	*15.44 (14.71–16.17)*	*Δ +0.94 (0.40) p = 0.017*
SU	*17.45 (17.06–17.84)*	*18.81 (17.74–19.88)*	*Δ +1.36 (0.58) p = 0.019*
SLJ	*129.80 (128.44–131.17)*	*130.36 (126.64–134.08)*	*Δ +0.56 (2.02) p = 0.782*
6 min	*996.23 (986.25–1006.22)*	*979.29 (951.07–1007.51)*	*Δ −16.94 (15.26) p = 0.267*

20-m Dash: 20 m; Balancing Backwards: BalBw; Jumping Sideways: JumpSw; Stand and Reach: St&R; Push-Ups: PU; Sit-Ups: SU; Standing Long Jump: SLJ; 6-min Run: 6 min.

Appendix C

Appendix Chapter 5

Table 1. Descriptive statistics for test scores by age and sex

Age	*Sex*	*Test*	*N*	*M*	*SD*	*med*	*min*	*max*
3-5	*Girls*	*JSW*	*4,277*	*13*	*6*	*12*	*0*	*51*
		SLJ	*4,250*	*84*	*22*	*85*	*25*	*175*
		BBW	*4,177*	*18*	*11*	*17*	*0*	*48*
		SaR	*4,126*	*3*	*6*	*3*	*-16*	*22*
	Boys	*JSW*	*4,186*	*13*	*6*	*12*	*0*	*50*
		SLJ	*4,118*	*89*	*23*	*90*	*29*	*171*
		BBW	*4,052*	*16*	*11*	*14*	*0*	*48*
		SaR	*3,991*	*1*	*6*	*2*	*-19*	*20*
6-10	*Girls*	*6min*	*9,493*	*869*	*139*	*868*	*500*	*1305*
		JSW	*10,194*	*26*	*8*	*26*	*0*	*52*
		20m	*9,663*	*4*	*0*	*4*	*3*	*6*
		SLJ	*10,238*	*119*	*22*	*119*	*29*	*190*
		SU	*9,689*	*16*	*6*	*16*	*0*	*33*
		BBW	*10,049*	*32*	*11*	*33*	*0*	*48*
		PU	*9,720*	*13*	*5*	*12*	*0*	*27*
		SaR	*9,944*	*3*	*6*	*3*	*-16*	*22*
	Boys	*6min*	*9,862*	*937*	*161*	*938*	*500*	*1433*
		JSW	*10,604*	*26*	*9*	*26*	*0*	*52*
		20m	*10,073*	*4*	*0*	*4*	*3*	*6*
		SLJ	*10,652*	*127*	*23*	*128*	*32*	*203*
		SU	*10,152*	*17*	*6*	*17*	*0*	*35*
		BBW	*10,416*	*29*	*11*	*30*	*0*	*48*
		PU	*10,133*	*13*	*5*	*13*	*0*	*28*
		SaR	*10,301*	*0*	*6*	*1*	*-19*	*20*

JSW: Jumping sideways; SLJ: Standing Long Jump; BBW: Balancing backwards; SaR: Stand and Reach; 6min: 6-minute Run; 20m: 20 m sprint; SU: Sit-Ups; PU: Push-Ups