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Article

Digital technology and child development: Theoretical basis and literature review from economic and biomechanical perspective

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Abstract: This review examines the impact of digital technology on child development, integrating economic and biomechanical perspectives. I reviewed existing literature, drawing upon human capital theory, skill formation theory, and parenting style theory, to establish a comprehensive framework for understanding this multifaceted issue. The current body of research suggests a concerning trend: Increased digital technology use often coincides with reduced physical activity and increased sedentary behavior. This shift potentially alters the mechanical environment experienced by children's developing bodies, raising concerns about musculoskeletal development, motor skill acquisition, and long-term health outcomes. At present, there have been some studies in related fields, but there is a lack of overall review and integration. For better understanding and conducting studies, some suggestions were given: Investigations should focus on dose-response relationships between digital technology exposure and biomechanical outcomes, while also considering the influence of moderating factors such as age, sex, pre-existing conditions, and parenting styles. By clarifying the underlying mechanisms, we can inform the development of evidence-based interventions and guidelines to promote optimal physical development and ensure the well-being of children in the increasingly digital world.

Keywords: digital technology; child development; human capital; biomechanics

1. Introduction

The rapid proliferation of digital technology has profoundly reshaped childhood, transforming how children learn, play, and interact with the world, raising concerns about its potential impact on development, particularly physical health. Childhood is a period of rapid growth, where mechanical forces generated during movement and physical activity are essential stimuli for bone growth and remodeling, muscle development, and the maturation of motor control. Fundamental motor skills, like walking and jumping, are not only crucial for physical health but also underpin more complex movement and participation in sports and recreation [1,2], directly relating to human capital formation.

However, the increasing prevalence of digital devices among children, leads to a significant shift: Sedentary screen time often replaces traditional play and physical activity, potentially altering the crucial mechanical environment experienced by developing bodies. Prolonged sitting, often in suboptimal postures, could impact spinal development and increase musculoskeletal problems. Reduced weight-bearing activities may negatively affect bone mineral density. Altered sensory input and motor output from digital interaction, compared to real-world experiences, could influence the development of neural circuits controlling movement.

While existing research explores some aspects of digital technology's impact on cognitive and social development, a significant gap exists in understanding the underlying biomechanical and cellular mechanisms. Many studies report correlations, but few directly investigate the causal pathways involving mechanical forces, cellular responses, and molecular signaling. For example, while some studies suggest a negative impact of screen time on motor skills, the precise biomechanical factors and cellular responses remain largely unknown. Furthermore, integration of economic perspectives, like human capital and skill formation theories and the influence of parenting styles, is often lacking [3].

This review addresses this gap by synthesizing literature on digital technology's impact on child development, emphasizing physical development and biomechanics, and integrating insights from human capital, skill formation, and parenting style theories to provide a holistic framework.

2. Theoretical basis

2.1. Human capital theory

Human capital theory regards knowledge, ability, health, etc. embodied in people as a kind of capital, that is, production factors, and provides an important research perspective for many economic phenomena. After continuous exploration by scholars in this field, human capital theory has been widely used in various fields, providing theoretical and practical supplements for many economic phenomena that cannot be fully explained by material capital, such as income gap, economic growth and technological progress.

As a crucial part of human capital, physical capabilities are essential for human development, health, and overall well-being. Biomechanics, the study of mechanical principles applied to biological systems, plays a crucial role in understanding physical capabilities. Investing in children's physical development and motor skills can have long-term benefits for their health, productivity, and quality of life.

Therefore, understanding the impact of digital technology on physical development and biomechanics is crucial for optimizing child development and promoting long-term health and well-being. This requires considering the diverse ways in which digital technology can influence children's physical development and incorporating biomechanical factors into human capital theory.

In the classic human capital theory, scholars such as Theodore Schultz and Gary Becker systematically discussed human capital theory from many macro and micro perspectives such as economic growth, income distribution, and human capital investment decisions [4,5]. Their pioneering work constructed the prototype of the modern human capital theory system and opened up an important research direction for economics. Subsequently, scholars such as Paul Romer and Robert Lucas endogenized technological progress into the economic growth model, further explaining the importance of human capital in promoting economic growth. Since then, relevant research on human capital has continued to expand, and its role and mechanisms in many fields such as wage gap, innovation and entrepreneurship, and regional development have also been gradually discovered by scholars.

Human capital is carried by people and is more difficult to measure than material capital. Relevant studies on human capital continue to emerge, and the measurement methods of human capital are also constantly developing. When exploring the different roles of human capital, the measurement methods used by existing studies are also different. When analyzing the impact of human capital on economic growth, scholars mainly use the indicator method, cost method and income method. The indicator method is to quantify the human capital of a region using indicators such as average years of education, school enrollment rate and adult literacy rate. The cost method mainly measures human capital based on direct expenditures and indirect costs related to education. The income method requires estimating the present value of the total income generated by an individual or the total population in a region during the remaining life. With the development of statistical methods, in addition to the above methods, many micro studies have cut in from the perspective of ability and used cognitive ability and non-cognitive ability to measure human capital. Compared with indicators such as education, cost and income, the measurement method centered on ability can more effectively measure personal human capital.

The role of human capital is important and extensive. Therefore, investing in human capital to improve personal productivity and social welfare has become a key research direction in the economics community. According to Schultz, by investing in human capital in education, training, health and migration, human capital or the efficiency of human capital utilization can be improved, thereby obtaining personal advantages in terms of job opportunities, work efficiency or income [6]. Jacob Mincer of the same period conducted a series of studies on school education, on-the-job training and work experience as important factors affecting personal income, and constructed the famous Mincer income equation, which promoted people's understanding of the returns on human capital investment and laid an important foundation for the study of the rate of return on education. With the continuous expansion and deepening of related research, educational economics has gradually developed into an independent discipline. In addition, health, as a kind of human capital, has also been widely concerned by scholars. Michael Grossman constructed a human capital model of health demand based on the family production function, regarded health as a durable capital that increases with investment, and proposed that consumers have dual motivations for investment and consumption in health. He found that health investment through medical care, exercise, diet, smoking and drinking can affect health stock, and conducted a series of studies on this basis. Some scholars have also explored the role of healthy human capital in education, economic growth, and skill formation.

Human capital is usually divided into general human capital and specific human capital. Becker found that the marginal productivity improvement effect brought by on-the-job training (OJT) varies from company to company, and based on this, he divided training into general training and specific training [7]. This classification idea has been widely accepted by the academic community and gradually developed into an important branch of human capital theory research, triggering a series of discussions. Since Becker's classification criteria are based on company settings, the human capital generated by general training and specific training are respectively called general human capital and company-specific human capital by scholars. Later, Gibbons and Waldman proposed task-specific human capital. They believe that the human capital obtained by individuals at work is based on the specific tasks performed, not the specific company. Therefore, when such human capital is accumulated, many companies will attach importance to the value of these human capital. And they pointed out that task-specific human capital is of great significance to issues such as job design, labor mobility, labor demand and business strategy [8].

In the digital age, with the continuous development and popularization of digital technology, the versatility of digital skills is constantly increasing, and they are in play anytime and anywhere. Individuals' digital skills will not only affect their learning and work efficiency, but also affect their way of obtaining information, analyzing problems and making decisions, and will also affect their social interactions.

The impact of digital technology on individuals is diverse, and it is not comprehensive to understand the relationship between digital technology and people only from the perspective of digital skills themselves. Because this impact is not only reflected in certain specific tasks or jobs, but also affects the overall labor productivity of individuals. From the perspective of human capital, digital human capital can be regarded as a kind of capital embodied in workers. By investing in digital human capital, labor productivity can be improved, thereby increasing future benefits. Compared with digital skills, digital human capital can better describe the production factors that workers have in the digital age.

Some scholars have conducted research based on the concept of digital human capital at the enterprise and social levels. Bach et al. found that digital skills training can enhance the digital human capital of disadvantaged groups, help them use digital technology to participate in social activities and improve their economic level, thereby playing a role in narrowing the digital divide [9]. Grimpe et al. believe that in the current business environment, digital human capital is one of the key factors that determine a company's competitiveness, and point out that compensation, personal learning and development opportunities, and the digitalization level of the company and the region are all important reasons that affect the retention of relevant talents [10].

This paper aims to explore the impact of digital technology on children's development, which is essentially a study of individual development from the perspective of human capital investment. Human capital theory emphasizes the role of people as capital in economic activities, making human capital investment activities widely valued. The macro aspect provides direction for competition between countries, especially the catch-up of developing countries with developed countries. The micro aspect provides a path for individual development and a reasonable explanation for income inequality between individuals. Child development is an important stage of individual development and a critical period for human capital investment and formation, which has an important impact on the accumulation of individual human capital. As the most important theoretical basis of this article, human capital theory has played a guiding role in determining the research problems of the article, clarifying the research significance, designing research methods, interpreting research results, and proposing policy recommendations.

2.2. Skill formation theory

Skill formation is the most important part of children's development and an important factor in promoting children's development. The study of skill formation theory began with human capital. The role of human capital has become increasingly prominent. How to improve human capital more effectively, that is, the study of the effect of human capital investment has gradually become one of the focuses of scholars. Personal skills are the key component of human capital. Different types of investment strategies at different ages have very different effects on improving personal skills. Based on the continuous deepening of research on this issue, skill formation theory has gradually been formed. The rise of research in this field is mainly driven by a series of studies by scholars such as Cunha and Heckman.

Cunha et al. [11] and Cunha and Heckman [12] divided the life cycle and childhood into multiple stages, and constructed a life cycle skill formation model based on the self-productivity of individual skills and the complementarity of human capital investment. They pointed out that the level of individual skills at a certain stage of the life cycle will affect the subsequent development of their skill levels, that is, individual skills are self-productive. In addition, early investment helps to improve the efficiency of later investment. If only early investment is made without subsequent investment, early investment will not generate returns, that is, human capital investment is complementary. Their findings are an explanation of the results of a large number of empirical studies, and provide a theoretical framework for the field of skill formation, which helps people understand the importance of early investment and the relationship between genetic factors and later investment in individual skills, and also emphasizes the important role played by the family. Heckman pointed out that the early environment of children has a profound impact on their development and achievement. The formation and development of cognitive, language, social and other skills, including health, influence each other, and have higher investment efficiency in specific sensitive periods [13]. In particular, the importance of early childhood education in narrowing the skill gap and its long-term development is emphasized. Cunha et al. analyzed the multi-stage production function model of individual skills and found that investing in early childhood can achieve more returns than investing in late childhood, and pointed out that for most disadvantaged groups, it is best to invest more in early childhood to narrow the gap. In addition, they found that in the later stages of the life cycle, the substitutability of cognitive skills decreases, while the substitutability of non-cognitive skills in the life cycle remains roughly the same at all stages [14]. Francesconi and Heckman emphasized the importance of parental investment and family environment in early childhood development, as well as the important value of early intervention in promoting the skill development of disadvantaged children [15].

Based on the collation of the above research, the skill formation theory is mainly based on the multi-stage production function model, which explores the process of personal skill formation. In particular, the investment return gap between early childhood and late childhood, and the substitutability of skill formation at different life stages.

2.3. Parenting style theory

Parenting style theory originated in the 1960s. Developmental psychologist Diana Baumrind observed the interaction between parents and children and divided parents' parenting styles into three categories: Authoritarian, permissive, and authoritative [16]. Subsequently, Maccoby and Martin expanded on Baumrind's research and added neglectful as the fourth type of parenting style. These four types constitute the current mainstream classification standard for parenting styles [17].

With the further development of interdisciplinary integration research, economists began to study the parenting style factors in parenting behavior. As a pioneer in family economics research, Becker systematically analyzed parents' parenting behavior using the economic paradigm. He regarded babies as "durable consumer goods" and pointed out that parents not only have to pay monetary costs, that is, direct costs, in the process of raising children. At the same time, they also have to bear the loss of income caused by reduced working hours due to raising children, that is, indirect costs. Babies can provide emotional utility to their parents, and more importantly, parents will also use their children's utility as part of their own utility, which is a manifestation of altruism. Parents make decisions on fertility and parenting methods under budget constraints based on the goal of maximizing utility that includes altruism.

Parenting style theory is also used by economists as a theoretical basis for building economic mathematical models to evaluate the impact of different parenting styles on children's ability development. Doepke and Zilibotti constructed an economic model of the impact of parenting style on children's future. They believe that parents' parenting style affects children's choices in two ways: One is to shape children's preferences, and the other is to directly limit children's choice sets. And pointed out that parents' decisions are affected by multiple factors such as technology, time, and money. The article also provides suggestions for the education of future children [18]. Weinberg proposed to use monetary incentives as a parenting method to study its impact on children, and proposed an incentive model to explore the impact of income on children's future development. He found that high-income families will influence their children's behavioral abilities through monetary incentives. On the contrary, low-income families rely more on non-monetary incentives (such as corporal punishment), which leads to limited behavioral ability of children, thus having a negative impact on income [19].

Parents' parenting style will affect the development of their children in many areas. In terms of academic performance, parents' parenting style has a strong positive correlation with children's grades. Generally, authoritative parents are more likely to cultivate children with good academic performance [20]. In the field of health, scholars have found that improper parenting style can cause obesity and oral problems in their children [21]. Extreme parenting style will also affect the crime rate and physical and mental health of future children. Deviations in family parenting style are widely considered to be one of the most important factors affecting children's crimes in adulthood [22].

In general, a systematic review of the above theories will help the growth of children, and provide a theoretical basis for the formulation of relevant policies and the selection of family parenting strategies.

3. Literature review

3.1. Child development

Research on child development involves multiple disciplines, including economics, psychology, sociology and education. This part mainly reviews relevant research in economics, especially in the field of labor economics. According to human capital theory and skill formation theory, children's development in skills, education, etc. will affect their labor market performance and economic output, and investing in childhood will help improve the economic well-being of individuals and society. Child development and human capital are closely linked. Human capital investment is an important means of children's development, and childhood is a critical stage for human capital accumulation. Therefore, child development, as an important topic in labor economics, has long attracted the attention of many scholars.

Cognitive abilities and non-cognitive abilities are important components of children's development. Scholars have explored the impact from different perspectives such as parental investment, school type, and peer effects. Del Boca et al. pointed out that the time parents invest in their children will significantly affect children's cognitive development, especially in early childhood, and the improvement effect of time investment is stronger than that of money investment [23]. Nghiem found that children's attendance at private or public schools had little impact on cognitive and non-cognitive skills [24]. Del Boca et al. expanded the subject of investment from parents to children themselves, and found that children's investment in themselves during adolescence is more important than the mother's investment [25]. Chinese scholar Cai et al. concluded based on random class assignment data that a higher proportion of only children can significantly improve the academic performance of the class, but it will have a negative impact on mental health and social adaptability [26]. Li et al. believe that China's preferential housing policies have reduced children's cognitive and non-cognitive abilities [27].

Academic achievement is a typical measure of human capital and a key factor in children's development. Based on the production function of children's cognitive achievement, Todd and Wolpin discussed in detail the production process of children's cognitive skills, analyzed the impact of family, school environment and race on children's mathematics and reading test scores, and studied black, white and Test performance gaps among Hispanic children, and pointed out that differences in maternal ability and family investment are important reasons for the achievement gap between races [28]. Cui et al. used the time and space differences in the implementation of China's compulsory education law and found that improving maternal education can significantly increase adolescents' school enrollment rates and mathematics test scores, and can improve adolescents' mental health and reduce the possibility of being underweight. It was also pointed out that family resources, parenting styles and maternal emotional factors may be potential influencing mechanisms [29].

There are also many scholars who have explored child development issues from other perspectives. Deuchert and Felfe found that natural disasters represented by typhoons will have a lasting negative impact on children's education, but the impact on health is not significant, and pointed out that there will be a stronger negative impact on disadvantaged children [30]. Cesarini et al. found, based on Swedish lottery winning data, that major wealth shocks may increase children's hospitalization rates while reducing children's obesity risk, without having much impact on children's long-term academic performance and skill development [31]. Felfe and Lalive believe that moderate expansion of early childhood care can improve the language skills of boys and immigrant children and the motor skills of children [32]. Zhang et al. found that there are significant regional and economic gaps in the growth and development levels of young children in China [33].

Physical development and biomechanics are crucial aspects of child development. Biomechanics plays a crucial role in understanding physical development, including motor skills, coordination, and posture. Investing in children's physical development can have long-term benefits for their health, productivity, and quality of life.

Schoenau and Frost emphasized the importance of mechanical loads on bone development during the development of children and adolescents [34]. Fisher et al. found that there is a significant correlation between basic motor skills and daily physical activity levels, which provides a basis for intervention in children's motor skills from a biomechanical perspective [1]. Stodden et al. proposed a developmental relationship model between motor skills and physical activity, emphasizing the importance of early motor skill development [35]. Lubans, et al. comprehensively reviews the current status of research on children's motor skills and related research on cellular biomechanics, including assessment methods and intervention strategies [2].

3.2. Digital technology and child development

The impact of digital technology on children's development occurs on multiple levels. Among existing studies, the impact of the use of digital technologies and specific types of applications has received the most attention. Some scholars have found that the use of digital technology can promote the development of children's cognitive abilities [36]. Cristia et al. also found that the increase in computer use did not significantly improve children's academic performance, but it may have a positive impact on cognitive abilities [37]. In addition, some scholars have pointed out that although digital technology can improve children's language skills, it may have a negative impact on their motor abilities [38].

In terms of specific applications, the impact of social media use on children's development has long attracted the attention of many scholars. Fairlie and Kalil pointed out that the use of computers not only increases children's activities on social networking sites, but also increases their time for offline social activities, and computer ownership does not reduce the proportion of students participating in extracurricular activities, nor is it significantly Reduce their participation in school activities [39]. Barrot stated that social media has had a positive impact on language learning [40]. However, some scholars have found that social media may cause depression and psychological problems in children and adolescents, and pointed out that these effects vary widely between countries [41,42].

The application of digital technology in education is also one of the focuses of scholars' attention. Dorris also pointed out that the use of digital devices in the teaching process can improve children's literacy and numeracy scores [43]. Bianchi et al. further studied and found that computer-assisted learning may have an impact on children's long-term development. It can improve students' educational attainment, labor performance and computer usage, and points out that computer-assisted learning can effectively narrow the urban-rural education gap [44]. Bulman and Fairlie reviewed a large number of studies on the impact of information and communications technology (ICT) investments, computer-assisted instruction (CAI) applications, and home computer use on educational outcomes [45]. They found that much of the current empirical evidence is based on the positive effects of digital technologies that provide students with additional study time or financial supplements. However, they also point out that in theory, investment in technology will crowd out traditional family education or classroom activities, so the effect may be uncertain. Regarding the impact of home computer use on educational outcomes, they found that the results of earlier studies were mostly positive and a few negative. Recent results based on randomized controlled trials are often very small or even have no effect. And the research objects have a tendency to gradually change from developed countries to developing countries.

David et al. found that new technologies have led to a significant increase in the likelihood of children suffering from neck diseases, and they have made suggestions from a biomechanical perspective [46]. The study of Suggate and Martzog and Liu et al. show that media use is associated with poorer tactile and fine motor abilities but was associated with better visual shape discrimination [47,48]. Some studies found that the use of digital technology can reduce muscle mass to a certain extent and lead to a series of health problems [49–51]. In addition, some studies have found that the use of digital technology can have adverse effects on children's bone development [52,53]. A analyzes the impact of body position on the musculoskeletal structure of the neck when children use smartphones from a biomechanical perspective [54].

The development of digital technology is also accompanied by the problem of digital divide. Salemink et al. found that the digital infrastructure gap between urban and rural areas is growing, and lower education and skill levels in rural areas also limit the use of digital technologies [55]. Chen and Price believe that providing computer skills training to teachers can help bridge the digital divide among children [56].

4. Conclusion

This review synthesized multidisciplinary literature to examine digital technology's impact on child development, emphasizing the critical, yet understudied, biomechanical implications. This study integrated economic, psychological, and biomechanical perspectives, revealing a significant gap: A lack of understanding of the cellular and molecular biomechanical mechanisms underlying observed effects. While evidence suggests increased screen time and reduced physical activity may negatively affect musculoskeletal development, motor skills, and long-term health, the precise causal pathways remain unclear.

The shift in children's activities, driven by digital technology, presents a altered mechanical environment, raising crucial concerns about skeletal and motor neural development. As highlighted from human capital prospective, these physical and biomechanic changes have impact to children's long term development. To address this, future research must move beyond correlation and directly investigate the cellular and molecular responses to these altered biomechanical conditions.

Therefore, there are some suggestions: 1) Research should employ rigorous experimental designs combining biomechanical assessments (motion capture, force plates) with cellular/molecular analyses (gene expression, protein assays, mechanotransduction) in relevant cell types; 2) studies should investigate the relationship between digital technology use (type, duration, content) and specific biomechanical/cellular outcomes; 3) research should consider factors like age, sex, pre-existing conditions, and parenting styles as potential moderators.

By elucidating these mechanisms, we can develop evidence-based interventions and guidelines to mitigate potential negative impacts and promote optimal physical development in the digital age.

To translate this knowledge into action, we propose the following policy recommendations: Governments should increase investment in the positive application of digital technologies in education and healthcare. This includes developing high-quality, developmentally appropriate digital educational resources and psychological counseling platforms specifically designed to support children's physical and mental well-being.

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