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A FUZZY DELPHI STUDY OF THE FACTORS ASSOCIATED WITH STATIC PHYSICAL WORKLOAD IN CHILDREN

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Abstract

Background: Static physical workload refers to the strain that arises from maintaining fixed postures for extended periods. Without proper management, this type of workload can contribute to muscular fatigue, discomfort, and long-term health complications. As a multi-dimensional concept, static physical workload poses challenges for achieving valid and reliable evaluations. Children are particularly vulnerable to adverse effects of imbalanced physical workload due to ongoing physical growth and development, prolonged sedentary activities, and diverse anthropometrically unmatched environments.

Objectives: The current research aimed to identify, classify and prioritize key factors influencing physical workload in children while being engaged in sedentary tasks, through an integrated Fuzzy Delphi technique.

Methods: First, an extensive literature review was performed to create an initial list of potential contributing factors. Next, a panel of fourteen experts from various academic and clinical domains evaluated the previously shortlisted factors. Last, Fuzzy Delphi method was employed to convert experts' qualitative assessments into quantitative data, allowing for accurate ranking of factors.

Results: The analyses revealed that posture (0.73) and task duration (0.70) were the most significant predictors of static physical workload in children, followed by sitting type (0.64), anthropometric match (0.62) and sedentary behavior (0.59). On the contrary, demographic factors such as age (0.36) and gender (0.35) had a minimal impact on postural strain.

Conclusions: The study highlights the importance of addressing posture and time management, as well as proper seating arrangements for sedentary tasks, to reduce static physical workload in children. Interventions targeting these factors are crucial for preventing long-term musculoskeletal disorders and promoting healthier physical development.

Keywords: Children, Posture, Musculoskeletal Development, Fuzzy Logic

1.Introduction

In recent years, increasing attention has been paid to the physical health of children and adolescents as one of the most vulnerable groups in society, particularly regarding physical activities. One of the key components in this field is **static physical workload**, which can have long-term effects on muscle development, skeletal structure, and the overall health of children [36]. Unlike dynamic workload, which involves active and repetitive movements, static workload involves maintaining a fixed body position for a specific duration and may lead to muscular fatigue, musculoskeletal injuries, and developmental disorders in early ages [37]. Numerous studies have shown that prolonged static postures in environments such as school, home, and during the use of technology can lead to problems such as back pain, early fatigue, and reduced mental focus [38]. Moreover, accurately assessing static workload in children is challenging due to physiological, behavioral, and psychological differences compared to adults [39].

In this context, the **Fuzzy Delphi Method (FDM)** has emerged as an effective tool for identifying and prioritizing factors affecting static workload in specific populations such as children. This method, by analyzing expert opinions and incorporating uncertainty in judgments, facilitates scientific consensus under complex conditions [40]. Given the importance of identifying the factors influencing static workload in children, the aim of this study is to utilize the Fuzzy Delphi approach to identify, categorize, and analyze these factors from the perspective of experts in health, education, and physical training.

The concept of static workload refers to activities in which muscles remain in a contracted state without significant movement. This type of workload often occurs during activities such as prolonged sitting, standing without movement, and working with digital devices [41]. In children, such conditions may result in increased muscle tension, reduced blood flow, and ultimately, early fatigue [42]. According to biopsychosocial models, static workload can be classified into three main categories: **physical factors** (such as posture, duration of activity, and environment design), **psychosocial factors** (such as stress, motivation, and parental supervision), and **environmental factors** (such as furniture type, lighting, and physical space) [43]. In the literature, various models have been proposed for workload analysis, including REBA (Rapid Entire Body Assessment) and RULA (Rapid Upper Limb Assessment). However, these tools have primarily been developed for adults and their accuracy in child populations is questionable [44]. To overcome the limitations of existing tools, this study adopts the **Fuzzy Delphi Method**, which combines classical Delphi techniques with fuzzy logic, allowing for the use of subjective and expert knowledge in uncertain situations [45]. Furthermore, the fuzzy approach enables a more nuanced analysis of subtle differences in expert views [46].

From a theoretical perspective, this study is grounded in theories of physical and mental workload, which emphasize that sustained, non-ergonomic postures can lead to chronic disorders in the long term [47].

2. Research Background

Static postural load is among the key elements, having a significant impact on physical growth and development. Theoretically, it is defined as the strain placed on individual’s body, while maintaining a fixed posture for extended time periods, whether sitting, standing, or holding a specific position (1). This type of workload can lead to muscular fatigue, discomfort, and long-term health issues, if not managed properly. Unlike dynamic movements, which involve shifting positions and varying muscle use, static workloads create sustained tension in specific muscle groups, leading to reduced blood circulation and an increased risk of musculoskeletal disorders (2).

With reference to children, static physical workload assumes even greater importance. Fundamental physical changes , growth and formation of spinal curves, puberty, and essentially long hours of sedentary work, are specific conditions experienced almost simultaneously by this age group. In a recent cross-sectional study, Santos et al., reported a prevalence of more than 27% of back pain in

children aged 6 to 12 years, being related to long hours of screen time, and inappropriate design of backpacks (3). Likewise, the findings of De Inocencio's research indicated a significant increase in musculoskeletal pain, from 3% at the age of three to more than 30% at 14 years of age (4).
Of the main factors affecting static physical workload, are the angular positioning of body segments in 3D space, duration of time the body is maintained in a specific posture, patterns of mass distribution in different body parts, along with the forces applied to the body from external environment or vice versa. Accordingly, detailed examination of such influential factors would pave the way to better understand dimensions of acute and chronic musculoskeletal disorders, correctly estimate muscular loads and joint torques, and accurately compare the existing physical conditions with the corresponding standards.
Evidently, lack of monitoring and strict control measures in this regard increases the possibility of developing physical conditions (5), and even emotional problems (6), in children. Not surprisingly, this would impose unjustified costs on families and governments. Bevan specified a significant 2% expenditure of the total Gross Domestic Product in Europe (7). Therefore, commitment to implementation of the first and second levels of health prevention (8), highlights all effective clinical measures to control physical workload experienced by younger individuals, particularly children.
As a multi-dimensional concept, static physical workload poses challenges for achieving valid and reliable evaluations (1). Diverse personal, postural and environmental factors contributing to static physical workload have been referenced in the literature (8, 9). However, these elements have primarily been discussed alongside each other, requiring an integrated approach for precise evaluations. Besides, identification of the factors has mainly been nonspecific, requiring a defined method and a proper arrangement to assist clinicians and researches in developing accurate forecasting models. Furthermore, classification of the factors has not been associated with specific clinical contexts, indicating potential unrelated views for predictions, and inadequate specified perceptions.

The current research was designed and implemented to identify, classify and prioritize the main factors contributing to static physical workload in children via an integrated Fuzzy Delphi method.

3. Methods

3.1. Fuzzy Delphi method

Fuzzy Delphi technique was employed to evaluate and prioritize the factors related to static physical workload in children. Fuzzy Delphi method is explicitly beneficial in exploratory and interdisciplinary research that helps early and accurate screening of the factors, before prioritization is implemented (10). This technique was originally introduced by Ishikawa to enhance the conventional Delphi method by addressing any imprecision and questions that may arise (11). Since Fuzzy Delphi approach features fuzzy set logic in utilizing the Delphi method, a brief explanation is presented in the following section.

3.2. Fuzzy set theory and logic

In a variety of circumstances, actual data is not sufficient to represent real-world situations (12). Fuzzy set theory is founded on the notion that the primary elements in individual’s opinions and decisions are not numbers and figures, but linguistic expressions (13). Thereby, terms or phrases are more appropriate to specify complex real-life situations. Fuzzy set logic was primarily developed by Lotfi A. Zadeh (14), with the intention to manipulate the uncertainty related to cognitive processes, thus addressing ambiguity and subjectivity in decision-making. Through this method, qualitative verbal assessments are coded to fuzzy estimates, which are ultimately converted into quantitative results.
A typical fuzzy set is a collection of objects, with a continuum membership grade value between numbers zero and one. Membership functions are utilized to detect the ambiguities of fuzzy sets with fuzzy logic (15). In the current research, due to simplicity and ease of computations, triangular fuzzy numbers (TFNs) were utilized to model experts’ opinions in numerical values. Triangular fuzzy numbers have membership function that is outlined via a set of three figures (l, m, u). The triplet

represents the lower limit or the lowest possible value (l), the middle or the most anticipated value (m), and the upper limit or the highest probable value (u), respectively (16). The triangular membership function $\mu_N(x)$ is presented in Equation 1, and is illustrated in Figure 1.

$$\mu_N(x) = \begin{cases} 0 & x < l \\ \frac{x-l}{m-l} & l \le x \le m \\ \frac{u-x}{u-m} & u \le x \le u \\ 0 & x < u \end{cases} \quad (1)$$

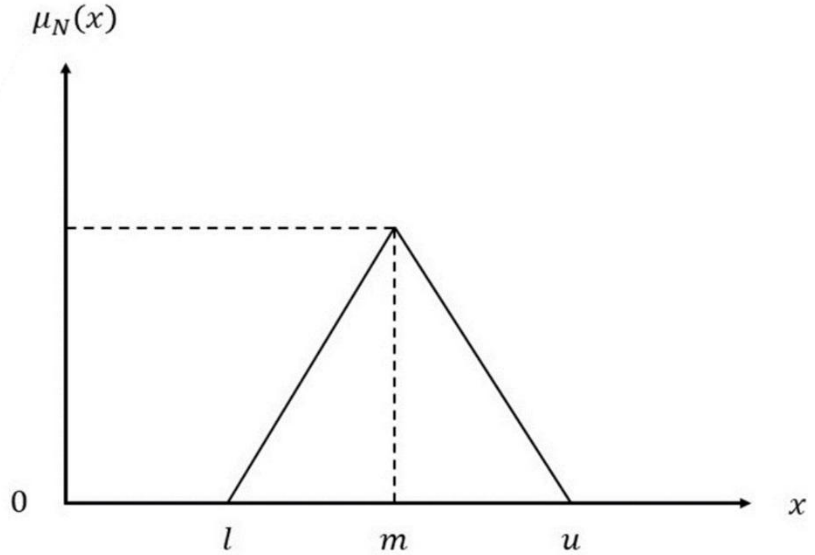

Figure 1: Membership function of a triangular fuzzy number N.

Given two TFNs, $\tilde{T}_1 = (l_1, m_1, u_1)$, $\tilde{T}_2 = (l_2, m_2, u_2)$, the equations 2-5 are valid:

$$\tilde{T}_1\ (+)\ \tilde{T}_2 = (l_1, m_1, u_1)\ (+)\ (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

$$\tilde{T}_1\ (-)\ \tilde{T}_2 = (l_1, m_1, u_1)\ (-)\ (l_2, m_2, u_2) = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad (3)$$

$$\tilde{T}_1\ (\times)\ \tilde{T}_2 = (l_1, m_1, u_1)\ (\times)\ (l_2, m_2, u_2) = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (4)$$

$$\tilde{T}_1\ (\div)\ \tilde{T}_2 = (l_1, m_1, u_1)\ (\div)\ (l_2, m_2, u_2) = (\frac{l_1}{l_2}, \frac{m_1}{m}, \frac{u_1}{u_2}) \quad (5)$$

3.3. Selection of experts

With reference to Delphi method framework in forming a panel of 10-18 experts (17), 14 specialists were invited to participate in the study. In order to create a sound representative sample, experts were required to hold continuing professional interest, have a current involvement and demonstrate a minimum of two years academic or clinical experience (18). The study group represented a wide variety of expertise with diverse backgrounds related to physical health and posture, including physiotherapy, pediatrics, orthopedics, ergonomics and biomechanics.

3.4. Identification of factors

A comprehensive literature review was performed to identify the factors contributing to static physical workload in children, followed by a detailed keyword analysis to manage overlapping and duplicates. The remaining items were then classified into three primary categories using a thematic analysis (19). Overall, 11 factors were characterized as being applicable to the context of static physical workload in children (Table 1).

Table 1: List of factors identified from the literature.

Category	Factor		Factor Description
Task-Related	T1	Task Duration (1)	Time span during which a static task is performed
	T2	Sitting Type (20)	Position of the body while sitting (in the current study, including Upright, Slumped, Slouched, and Forward Leaning)
	T3	Anthropometric Match (21)	Match between sitting furniture and specific body dimensions (Chair Seat Height vs Popliteal Height, Chair Seat Depth vs Buttock-Popliteal Length, Chair Seat Width vs Pelvic Width, Upper Edge of Backrest vs Sitting Shoulder Height, Desk Height vs Sitting Elbow Height)
Physical	P1	Posture (22)	Relative orientation of body segments in 3D space
	P2	Musculoskeletal Health (Function) (23)	Function and appearance of the Musculoskeletal system, based on pediatric Gait, Arms, Legs, Spine (pGALS) assessment checklist
	P3	Musculoskeletal Health (Appearance) (23)	
	P4	Body Composition (22)	Distribution of fat, muscle, bone, and other tissues that make up individual's body
	P5	Body Mass Index (24)	The metric for defining anthropometric height/weight characteristics in adults, and for classifying (categorizing) them into group.
Demographic	D1	Sedentary Behavior (25)	Any waking behavior characterized by an energy expenditure ≤1.5 metabolic equivalent, while in a sitting, reclining, or lying posture.
	D2	Gender (26)	The biological and physiological characteristics that define humans as female or male.
	D3	Age (27)	The period contemporary with a person's lifetime

3.5. Fuzzy evaluation of factors

The parameters entitled from the identification phase were precisely evaluated by the study panel via an online assessment form. The evaluators were tasked with providing qualitative assessments regarding each factor. They were also prompted to indicate relevant aspects that had not been explicitly mentioned in the literature. The phases completed to convert experts' qualitative evaluations into quantitative scores, enabling the ranking of each factor, are outlined in the following sections.

3.5.1. Transformation of linguistic scale into fuzzy numbers

Experts were requested to verify the impact of all the chosen factors, utilizing linguistic labels, using a five-point scale was for evaluations. The descriptions for each linguistic variable are listed in Table 2 and presented graphically in Fig. 2. In the expressions, "Impact" refers to the level of musculoskeletal discomfort that an individual might experience due to imbalances in a specified factor (28).

Table 2: Definition of the linguistic scale

Linguistic Expression	Fuzzy Number (l, m, u)
Very Low Impact	(0.00, 0.00, 025)
Low Impact	(0.00, 0.25, 0.50)
Moderate Impact	(0.25, 0.50, 0.75)
High Impact	(0.50, 0.75, 1.00)
Very High Impact	(0.75, 1.00, 1.00)

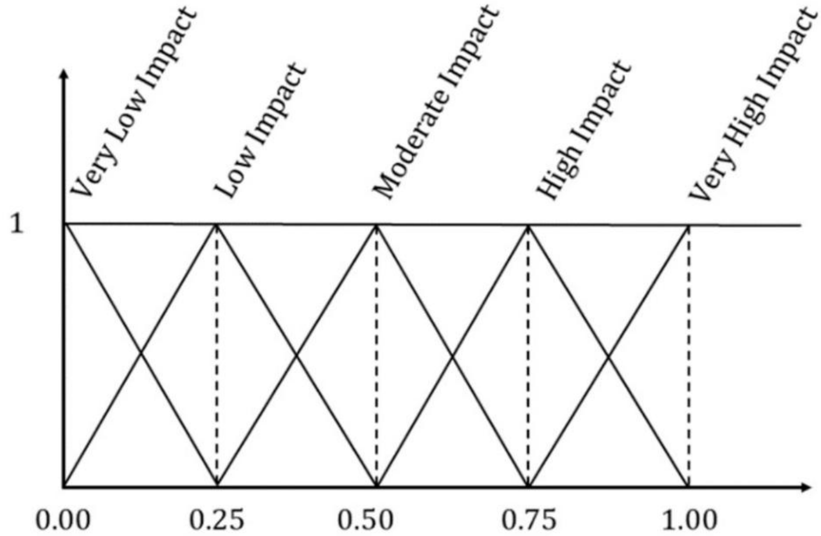

Figure 2: Fuzzy triangular membership functions.

3.5.2. Aggregation of scores

In order to integrate experts' reported weightings for different factors, the Similarity Aggregation Method proposed by Tzeng (29) was adopted in the study. Assuming the evaluation value of the significance of No. j factor given by No. i expert of n experts is:

$$\widetilde{w}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right), i = 1, 2, \dots, n, j = 1, 2, \dots, n, \quad (6)$$

then the fuzzy weighting $\widetilde{w}_j$ of No. j element is

$$\widetilde{w}_j = \left(l_j, m_j, u_j\right), j = 1, 2, \dots, n, \quad (7)$$

where

$$l_j = Min_i\{l_{ij}\}, \qquad m_j = \frac{1}{n} \sum_{i=1}^{n} m_{ij,} \qquad u_j = Max_i\{u_{ij}\}. \quad (8)$$

3.5.3. Defuzzification

The Center of Gravity method was employed to finalize the evaluation process (30), through which aggregated scores for each factor j were transformed from a triangular fuzzy number to a crisp value. As one of the most common approaches in defuzzification (31), this method does not introduce priorities of any experts, thus moderating possibilities of biased outcomes. The related formula is illustrated in Equation 9.

$$S_j = \frac{[(u-l) + (m-l)]}{3} + l, \qquad j = 1, 2, \dots, n. \quad (9)$$

4. Results

The global score of all predicting factors for static physical workload was computed as a triangular fuzzy number, and were subsequently transformed into a particular crisp value via defuzzification. The finalized scores and rankings are summarized in Table 3.

Among all evaluated factors, "P1: Posture" was recognized as the element having the highest impact (0.73). Also, "T1: Task Duration", "T2: Sitting Type" and "T3: Anthropometric Match" followed in the ranking with scores of (0.70), (0.64) and (0.62) respectively.

Likewise, “D1: Sedentary Behavior” (0.59) completed the top-five contributing factors. Experts emphasized that sedentary lifestyle and duration of time spent in static postures, was a relatively significant contributing parameter.
By comparison, “Musculoskeletal Health”, as regards to both function “P2” (0.49) and appearance “P3” (0.46) of individual’s musculoskeletal system, appeared to be moderately critical, with the former indicating higher impact. This was followed by “P5: BMI” (0.44), and “P4: Body Composition” (0.39).

Table 3: Factors’ ranking.

Factor		Fuzzy Number	Total Score	Rank
P1	Posture	(0.50, 0.75, 0.93)	0.73	1
T1	Task Duration	(0.46, 0.71, 0.91)	0.70	2
T2	Sitting Type	(0.41, 0.64, 0.84)	0.64	3
T3	Anthropometric Match	(0.39, 0.63, 0.84)	0.62	4
D1	Sedentary Behavior	(0.34, 0.59, 0.84)	0.59	5
P2	Musculoskeletal Health (Function)	(0.29, 0.48, 0.70)	0.49	6
P3	Musculoskeletal Health (Appearance)	(0.23, 0.45, 0.70)	0.46	7
P5	Body Mass Index	(0.25, 0.43, 0.64)	0.44	8
P4	Body Composition	(0.16, 0.38, 0.63)	0.39	9
D2	Gender	(0.11, 0.36, 0.61)	0.36	10
D3	Age	(0.18, 0.32, 0.54)	0.35	11

On the contrary, effects associated with demographic factors, “D2: Gender” (0.39) and “D3: Age” (0.35) were almost negligible in overall computation of static physical workload among children.

5. Discussion

The current study contributes to the physical health knowledge in three manners. Firstly, it presents an organized review and categorization of factors related to the concept of static physical workload in children, which is theoretically applicable to other age groups within different contexts. Secondly, it underlines the advantages of employing Fuzzy Delphi technique to approach ranking and prioritization within a given physical health domain. Thirdly, through focusing on a specific population segment, this research presents a more in-depth exploration in static physical workload topic, thus enhancing the level of accuracy compared to popular generic postural load assessment methods.
Research into the static physical workload in children often examines how various factors influence their comfort and health during sedentary activities. The top ranking of “Posture” implies that the study panel is mainly concentrated on postural habits adopted by children, which has also been highlighted in literature (32).
The correlation between posture and static physical workload is especially important when considering growth and developmental needs of children. Awkward and improper postures place undue strain on developing musculoskeletal structures, leading to issues such as pain, discomfort, and spinal deformities. This allows for hypothesis considering the relevance of postural health training to long-term physical well-being in children.
Likewise, recognizing “Task Duration” as the second highest influential factor in the study indicates the significance of proper allocation of time to various types of physical activity, as regards children.
This has also been confirmed through other observations in physical health domain (33). The association between task duration and postural load is closely linked to the amount of strain placed on the musculoskeletal system over time. As the duration of a task expands, particularly one that

involves sedentary activities, the postural load on muscles, joints, and ligaments also increases. This prolonged strain leads to muscular fatigue and compromised physical health.

Besides, two other critical predictors of static physical workload in this research are “Anthropometric Match” and “Sitting Type”. Anthropometric match refers to how well the dimensions of a child's body align with the design of their seating equipment. Meanwhile, the sitting type (slumped, slouched, upright and forward leaning positions in the current study) also impacts physical workload. Previous research indicates that when seating furniture and body dimensions are well-matched, children experience less physical discomfort and strain (34). Conversely, mismatches can exacerbate static physical workload, potentially leading to poor posture and increased fatigue. Understanding how these factors interact is essential for optimizing seating arrangements to support children's physical well-being during prolonged periods of sitting.

Additionally, “Sedentary Behavior” and poor postural habits in children often create a harmful cycle that impairs both concepts. Findings of the current study evidently address this issue. When children spend extended periods sitting, particularly in environments lacking proper design, they are more likely to adopt and maintain poor postural habits. This sedentary behavior limits physical movement, weakening core muscles and reducing flexibility, which in turn increases the risk of developing improper posture (25). This mutual reinforcement between sedentary behavior and harmful postural habits highlights the importance of promoting regular physical activities and teaching appropriate sitting techniques to reduce the adverse effects on children’s musculoskeletal health.

There are, however, certain inconsistencies regarding factors’ impact on static physical workload in the current research. The overall musculoskeletal health parameters were considered less significant as regards physical workload in children. This finding, apparently, is not in line with the general direction of the existing literature (35). A potential explanation is that, the concept of general physical health awareness has improperly been introduced in the study. As a result, individual’s attitude towards maintaining proper posture is underestimated in experts’ point of view. Besides, demographic parameters of age and gender were identified with minor impact on static musculoskeletal loads in the current research. Although, direct effect of such variables on physical workload has not been addressed frequently, trends and differences highlighted in the previous observations indicate the significance of physical growth and development factors as regards children (27).

6. Conclusions

Recognizing the importance of static physical workload in children is essential for fostering their overall physical health. Proper posture during sedentary tasks, combined with appropriate allocation of time, can significantly reduce the risk of musculoskeletal issues and improve performance. Additionally, ensuring an anthropometric match between children’s body dimensions and various types of furniture, promotes reasonable comfort, safety and health.

While slight variations in postural capabilities may arise as children grow, the overall impact of age on physical workload is minimal. Similarly, gender differences in postural stability and strength do not significantly influence how children respond to static tasks. Instead, it is crucial to focus on promoting appropriate physical activities and individualized approaches, to enhance posture. Evidently, proper allocation and prioritization of these factors, paves the way to more effective strategies in supporting children's physical development and well-being.

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