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Optimising Teacher's Comfort in Classroom: Prototype Design and Development of Vibrating Insole

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Abstract: Ergonomic interventions can optimise the interaction between humans and work processes, and are particularly important for school teachers due to the increased prevalence of musculoskeletal disorders (MSDs) among them. Long working hours, prolonged sitting, awkward postures, and repetitive movements can all result in MSDs, particularly in the lower extremities. This study tasks to create a prototype, incorporating a vibrating insole, tailored to meet the comfort requirements of school teachers. The study is divided into three Phases: Phase 1 (problem identification), Phase 2 (prototype development), and Phase 3 (prototype testing). This prototype's discomfort ratings were assessed using the Borg's scale. Initial testing was conducted to analyse the prototype's efficacy, with an emphasis on body discomfort ratings provided by teachers during one-hour teaching session. During the initial testing phase, the findings demonstrated a significant correlation between insole prototype comfort with vibrating for thigh, calf and ankle and feet discomfort rating ($p<0.001$) in this study. The prototype testing highlighted that school teachers' discomfort rating for ankle and feet showed significant reductions when tested with insole prototype compared to control insole ($p<0.05$). The prototype of insole with vibrating effect provides an alternate way to improve the ergonomic design of existing insoles while also reducing general body discomfort, notably for school teachers. However, thorough field, laboratory, and clinical testing is required to prove its efficacy in future.

Keywords: Product design specification, Insole, Vibrating, Comfort, School teacher

1. Introduction

Musculoskeletal disorders (MSDs) are a major issue among school teachers, with a rise in the prevalence of neck, shoulder, arm, and low back disorders. Several variables influence the prevalence of MSDs in teachers, including ergonomic risk factors, teaching posture, and psychological issues such as stress. According to research, MSDs are common among teachers, especially those who work in special education institutions or programmes. Teachers commonly experience MSDs affecting their lower back, neck, and upper extremities. Several factors impact the frequency of MSDs among teachers, including gender, teaching experience, lifestyle, and organisational determinants [1] – [4].

In fact, MSDs are a major issue for school teachers in Asian nations. MSD prevalence rates have been observed among school teachers in numerous Asian nations, ranging from 60.3% to 74.5% [1]. MSDs among teachers are caused by a lack of proper school structure, teachers' lifestyles, low pay, job overload, teaching posture, and psychological variables such as stress [2,3]. Throughout addition, a Chinese research of secondary school teachers discovered that 35.8% reported permanent upper limb discomfort, whereas 33.3% had experienced upper limb pain throughout their lives [4]. These findings emphasise the necessity of

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addressing the numerous risk factors linked with MSDs among school teachers.

According to Malaysian research, the frequency of MSDs among school teachers in Malaysia varies between 40.4% and 74.5%[1,2], [5]. Research on musculoskeletal diseases (MSDs) among Malaysian school teachers has shown that teaching posture has a significant impact on the prevalence of MSD. Female teachers at Terengganu elementary schools had a high frequency of MSDs (40.1%). The feet were the most afflicted body part, accounting for 32.5% in the past 12 months and 36.8% in the last seven days. Teachers' risk variables were examined, including shoe type and teaching postures. They are also more likely to have a greater prevalence of MSDs than existing results, owing to significant risk factors if no action is made to minimise MSD prevalence. The highest frequency of MSDs in feet indicated that teachers should be given with ergonomically tailored footwear to wear, especially during a teaching session that involved constant standing and repeated movement involving feet [6]. Besides that, a narrative review found that teachers may develop MSDs from exposure to ergonomic risk factors, such as teaching posture [2].

In fact, teaching is a career that requires extended periods of standing and is typically connected with an increased risk of physical discomfort and pain during the school day. Continuous standing can cause a steady decrease in posture over time. In order to relieve tension during a classroom session, teachers may assume a slouched posture and shift their weight from one foot to the other. Slouching causes a stationary posture, which leads to impaired focus and attention. If teachers maintain this unpleasant posture for a lengthy period of time, it can cause circulation problems such as swelling feet and legs. Furthermore, prolonged standing might result in partial immobility or stiffness in the thighs, knees, and foot [7].

To address these health issues among school teachers, some researchers suggested that insole treatments be implemented due to its applicability when applied to various types of footwear [8]. With the continued growth of the footwear business, methods using shoe insoles are gaining popularity, particularly in studies focusing on occupational groups who participate in extended standing, sitting, and repetitive physical motions at work [9]. Teachers' preferences and views of footwear have not been fully addressed, despite the fact that the lower extremities, such as feet, require maximal support of the entire body weight during prolonged standing. A teacher is deemed to have extended standing if they have been standing for more than half of the school day. As a result, teachers may have muscular soreness and discomfort at the end of the workday, especially if they wear inappropriate footwear [10].

In comparison to other professional sectors, less study has been conducted on footwear interventions for teachers, particularly those involving the use of vibrating insoles. Therefore, this study developed a shoe insole with a built-in vibrating effects to promote comfort to teachers during school sessions.

2. Materials and Methods

This study's design process consisted of three main phases that were derived from Figure 1 of Pugh's total design process model [11].

Phase 1 focused on identifying main ergonomic issues encountered by school teachers during teaching sessions and developing criteria based on past research and considerable literature. Phase 2 detailed the design and development process for the insole, which includes built-in vibrating effects. In Phase 3, the initial testing was carried out to determine the efficacy of the proposed prototype when compared to a control (non-vibrating) insole.

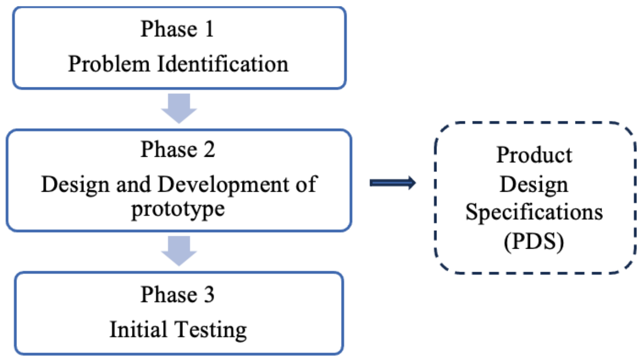

Figure 1. Product Design Specifications (PDS)

2.1 Phase 1: Problem Identification and Developing Criteria

During Phase 1, a comprehensive review of the literature and previous research was done to identify and explore ergonomic difficulties experienced by Malaysian school teachers. To construct a criterion list for prototype development, the research team studied and discussed on insights gained from prior research endeavors.

2.2 Phase 2: Designing and Developing a Prototype

This phase includes the generation of basic concepts and ideas, as well as the participation of engineering experts in discussions. The Product Design Specifications (PDS) was also constructed using the criterion list (inputs) from Phase one. The datum design was based on an existing vibrating insole product. It was used to evaluate design concepts against predefined criteria early in the design process. In this regard, a prototype from Hijmans et al. [12] was chosen as the datum because to its extensive study of efficacy in vibrating insoles. For prototype development, design was developed based on the list of criteria and PDS. The technician was actively engaged throughout the prototype development process, providing feedback and suggestions from the research team and expertise.

2.3 Phase 3: Initial testing

Preliminary testing was conducted on 20 subjects among school teachers. This involves comparing a control insole (no vibration) against vibrating insole prototype within the same control shoe. The insole prototype was evaluated using the same settings and schedules as the control insole, with a one-week interval.

2.4 Data Collection

During the data collecting phase, after getting permission for the prototype's safety and health requirements, first testing was conducted in a classroom setting with 20 teachers. Participants in this preliminary testing utilized the prototype throughout a one-hour class session and were instructed to complete the Borg's scale to measure body discomfort every 15 minutes. The researchers also observed and compared postures of school teachers between the control and insole prototypes. All data from the questionnaire were analysed using IBM SPSS (Statistical Package for the Social Sciences) version 27, which included both univariate and bivariate analyses. The study used a 95% confidence interval, 80% power, and p-values <0.05 were considered significant.

3. Results and Discussion

3.1 Phase 1: Problem Identification and Criteria List

In Malaysia, recent study in Terengganu has established the baseline data of MSDs for 12 months and seven days prevalence among primary school teachers with 40.1% in every part of the body. According to this study, the foot was confirmed to be the highest MSDs prevalence of all body sections, affecting 32.5% for the past 12 months and 36.8% for the past seven days for female school teachers [6]. Findings by Ng et al. [13] also indicated that the most MSDs discomfort among primary school teachers in Kota Kinabalu, Malaysia was at their neck/shoulder, followed by hips, bottom, legs, and feet (lower extremities) (48.9%), middle to lower back (48.4%), arms (40.7%) and lastly, at their hands/fingers (36.5%).

According to the findings of teachers' perceptions of footwear comfort, the prevalence of foot discomfort was 38.3%, with 29.8% in the forefoot, 20.1% in the hindfoot, and 15.6% in the midfoot [14]. When they stand, their feet and the floor's surface come into contact. The soles of the feet were strong as they landed on the earth. The foot sole may have an irregular and imbalanced effect, causing scattered plantar strain. These impacts alter the stress pattern imparted to the foot, stress can produce temporary or permanent stresses on foot tissues, resulting in foot pain. This can cause foot injuries or affect a person's general health [15].

Furthermore, this study offers researchers with useful insights into developing footwear interventions based on the perspectives of female school teachers who encounter difficult and extended static postures while carrying out their responsibilities on a daily basis. According to the findings, shoe insoles (51%) are preferred above alternatives such as anti-fatigue mats (20%), shoe massagers (15%), and footrests (14%). The rationale for this decision was that the interventions should not disrupt their activities, particularly in the classroom, where the process of teaching and learning might be lengthy [14].

A strong support shoe would benefit the rest of the body and may lessen the likelihood of experiencing back and leg discomfort. Proper footwear can alter the overall posture whether sitting or standing [16]. Subsequently based on these findings, Alias et al. [14] advocated that researchers to design comfortable footwear, specifically shoe insoles, with ergonomic intervention design, considering their daily teaching routine, which required walking, sitting, and standing for extended periods of time, as well as improving the comfort of lower extremities, particularly feet.

To address these health issues among school teachers, some researchers suggested that insole solutions be implemented due to its applicability when applied to various types of footwear [8]. Vibration by vibrating tactors can also help soothe the muscles around the sore site, more thoroughly minimizing pain and discomfort [16]. Thus, based on prior research and vast literature, Figure 2 summarized the ergonomic issues among Malaysian school teachers, as well as the input information of the insole features used in this study. Aside from that, contributions from technicians and engineering experts were discovered to aid in the development process during the selection and fabrication processes.

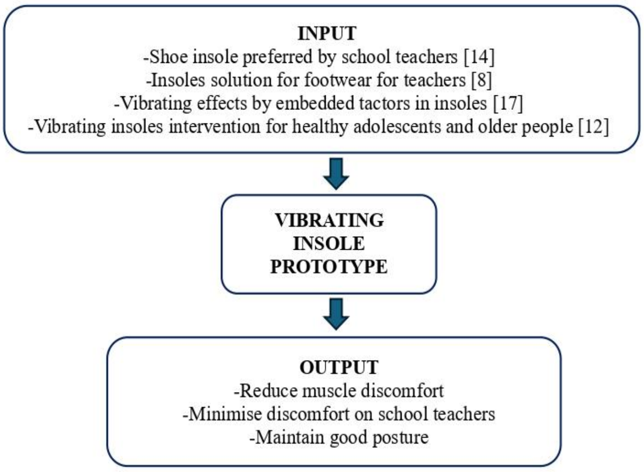

Figure 2. Ergonomic Issues among School Teachers towards Development of Prototype

3.2 Phase 2: Design and Development of Prototype

This phase was carried out with the ultimate objective of developing a prototype for a vibrating insole. Following the discovery of criteria in Stage 1, the research team met to debate and improve ideas for the prototype's design and development, with the goal of consolidating and improving the initial concept.

3.2.1 Product Design Specifications (PDS)

The prototype was developed considering a total of 13 PDS criteria. The criteria as listed below in Table 1.

Table 1: Criteria for Product Design Specifications

NO	CRITERIA	REQUIREMENTS
1	Performance	The vibrating insole prototype is a real-time system controlled by control box in order to not disturb any movement during normal working condition (sitting, standing, walking) and activities during teaching session
2	Environment	It can withstand hot and cold temperature and anti-bacterial insole material
3	Product life span	It can withstand up to five years with regular maintenance
4	Materials	Light, comfortable and relatively hard (Shore A50) and adapt well to vibration tactors
5	Ergonomics	Bottom layer consists of non-slip high performance and easy to operate, handle and maintain
6	Weight	Light weight material with 18mm thickness
7	Size	Come with three different sizes of insoles
8	Customers	School teachers
9	Aesthetics	Non-invasive product with minimal handling
10	Installation	Easily operated with control box and easily charged using a power bank. The prototype is wearable and mobile without disturbing any movement and activities during teaching session
11	Testing	In classroom testing session had been conducted • Observation of teachers' posture during the session • The Borg's scale had been used to rate discomfort rating while wearing prototype
12	Design time	• Conceptual design- 3 months • Prototype development-12 months
13	Target production cost	• Low cost • No competing products available on the market

3.2.2 Prototype Design and Development Process

During the conceptual design stage, a solution was developed to comply with the PDS. The prototype's design underwent finalization based on several proposed concepts, aiming to determine the most optimal design for development and subsequent testing in trial runs. According to Nixon et al. [18], technical priorities are determined using the Pugh matrix, and the design with the greatest overall score is chosen for final ranking. At this point, the most suitable concept was picked, kicking off the design process. Pugh's Total Design Method [11] was used to create a prototype adapted to respondents' demands in real-world circumstances. The most appropriate conceptual design was generated based on the Figure 3 for PDS criteria.

Figure 3. Vibrating Insole Prototype in Footwear

A two-layered vibrating insole was made from firm synthetic foam with a shore hardness of A50. Five vibrating C2 electromechanical tactors with a micro-cylindrical thickness of 7.9mm were placed into the middle layer of the insole to transmit vibrations to the feet's plantar surface. Vibration motors were not used as vibrating components in this study due to their restricted frequency range and set vibration amplitudes, which are reliant on the motor's design and have less individual adjustability than vibrating tactors [17].

Vibrating tactors were connected to a small control box and noise generators to provide mechanical stimulation to the feet's plantar surface. This technology reduced the need for direct human interaction, had a compact footprint, and was simple to maintain. The vibrating tactors used in this research ran on low voltage (up to 1.5V) and produced varying frequencies ranging from 40 to 120 Hz [19]. Furthermore, the tactors' vibration amplitude was automatically adjusted to improve comfort during teaching sessions. This feature allows for fine-tuning of the amplitude based on individual variances in tactile perception thresholds [17].

The insole was switched on, calibrated, and efficiently controlled using a control box with a light indication display [20]. An ideal vibrating insole prototype was developed using an assortment of vibrating tactors, a control box, and a noise generator to enhance comfort for the soles of the feet during various activities such as walking, standing, and sitting while minimising disruption to everyday routines. The control box controls this vibrating insole prototype in real time to minimise disruptions or movements during normal work situations (sitting, standing, walking) especially during teaching sessions in classroom.

3.3 Phase 3: Initial testing

Initial testing was conducted to analyse the prototype's efficacy, with an emphasis on body discomfort ratings provided by teachers during one-hour teaching sessions. Throughout the initial testing phase, the spearman correlation rho results (Table 2) concluded a significant correlation between insole prototype comfort with vibrating for thigh, calf and ankle and feet discomfort rating ($p<0.001$) in this study. There is strong positive correlation on ankle and feet part ($r=0.419$).

Table 2: Correlation between Prototype Comfort with Body Parts (Discomfort Rating)

Body Parts (Discomfort Rating)	Shoe Comfort	
	r	**p-value**
Neck/Head	0.090	0.484
Shoulder	0.062	0.228
Upper Back	0.031	0.642
Arm/Hand	0.083	0.504
Low Back	0.298	0.212
Buttock	0.019	0.542
Thigh	0.386	**<0.001***
Knee	0.066	0.202
Calf	0.377	**<0.001***
Ankle/Feet	0.419	**<0.001***

Table 3 also showed significant differences in discomfort ratings between the experimental and control groups for ankle and feet parts. During the one-hour teaching session, the insole prototype group (vibrating) had considerably less discomfort ($p<0.05$) than the control insole group (no vibrating) from 15 minutes until evaluation ended. The results from Wilcoxon signed-rank test highlighted that school teachers' discomfort rating for ankle and feet showed reductions when tested with vibrating insole prototype.

Table 3: Discomfort Rating among School Teachers

Time (minutes)	Median (IQR)		z-value	p-value
	Insole prototype (n=10)	**Control Insole (n=10)**		
15	0.3 (0.2,0.7)	1.0 (0.5,1.5)	-1.31	**0.041***
30	0.5 (0.3,1.0)	2.0 (1.5,3.0)	-2.46	**0.022***
45	1.0 (0.5,2.0)	4.0 (2.0,5.0)	-4.13	**0.013***
60	2.0 (0.9,3.0)	7.0 (4.0,9.0)	-4.58	**<0.001****

The vibrating insole prototype showed considerable decreases in discomfort ratings (according to Borg's scale), particularly in the ankle and foot regions when compared to other parts of the body. This indicates a direct and significant comfort advantage for these specific body areas. The observed decreases in discomfort in other bodily locations might be due to the systemic consequences of the body's reaction to stimulation. Given the interconnection of the body's reactions, relaxation in one location may spread to nearby regions, perhaps contributing to similar comfort benefits. As a result, it is fair to expect that mechanical stimulation provided by vibrating the insole, particularly in the foot sole area, might improve ankle proprioception, balance, and general body comfort [17].

Moreover, balance is critical for human movement since it is inextricably tied to a variety of activities. Impaired balance increases the likelihood of falls [21]. Notably, poor standing balance can cause discomfort and worse quality of life, affecting everyday activities [22]. In contrast, improved posture has been demonstrated to increase employee productivity while decreasing the risk of lower limb injury [23]. As a result, quick restoration of body stability and comfort using basic ergonomic solutions such as footwear insoles is critical [14].

The increased prevalence of musculoskeletal diseases (MSDs) affecting the feet emphasises the need of teachers having access to ergonomically designed footwear, particularly during extended teaching sessions that require repetitive standing and foot motions. These specialised footwear solutions should prioritise comfort, particularly in the lower extremities, in order to meet the unique demands of teachers. In recent years, little attention has been paid to the well-being of the lower limbs, despite their critical role in allowing teachers to maintain correct posture during teaching sessions and the school day [19].

The insole, as the inside component of footwear, acts as an important interaction between the shoe and the foot. Insoles serve an important function in restoring muscle alignment in the legs, which promotes comfortable walking, pain-free standing, and injury prevention. Finally, this study provides useful insights into footwear comfort, which might pave the way for the development of more sophisticated designs and interventions, notably shoe insoles for school teachers [14].

According to the findings of the survey of school teachers, 38.3% had foot discomfort, with a higher incidence in certain areas: the forefoot (29.8%), hindfoot (20.1%), and midfoot (15.6%) [14]. When standing, the feet make contact with the floor, and the soles absorb the impact of landing. This impact may result in an unequal distribution of plantar strain, potentially leading to aberrant stress patterns on the foot. Such tension can cause temporary or permanent strains on the foot tissues, adding to pain. This pain might lead to foot injuries or worsen general health [16].

Similarly, school teachers who are exposed to ergonomic risk factors such as extended standing, walking, and maintaining uncomfortable postures throughout the day consider long-term comfort when choosing footwear. Comfort is related to the kind of footwear, the nature of duties or activities, and the special demands of diverse workers, such as those in construction, postal services, and office environments. This emphasizes the possibility for tailored shoes developed to meet the needs of various vocations [24].

The design and choosing of shoes are heavily influenced by perceptions of comfort. Subjective assessments are critical for developing ergonomic footwear, especially for occupational groups predisposed to musculoskeletal diseases (MSDs). Consumers place a high priority on ergonomic design in footwear [25]. Hence, the considerable improvement in discomfort ratings among school teachers demonstrates the vibrating insole design's efficiency in providing foot support. The term 'support' refers to several features of footwear, such as 'supporting the knee,' 'designing and enclosing,' and 'supporting the foot arch.' Support is inextricably tied to comfort, as evidenced by the concept that 'the shoe must be comfy, and your foot should be adequately supported.' Proper arch support distributes foot pressure more evenly, which can reduce discomfort. Furthermore, a well-supported shoe can improve general body health, perhaps alleviating back and leg pain. Comfort is closely connected with cushioning, as indicated in words like 'cushioning your foot' and 'feeling like a pillow,' which contribute to a bouncy and springy experience when walking [15].

While the prototype concept is still in its early stages, it requires several testing and design modifications despite its usefulness and positive feedback. It has considerable potential for relieving muscle discomfort and improving posture. As a result, additional testing of the vibrating insole prototype should include a thorough assessment in lab, clinical, and field settings. Future research efforts may focus on analysing reported pain levels and spinal angle posture to give a thorough comparison between the control insole and the insole prototype with vibrating effects.

4. Conclusion

This study successfully developed and constructed a prototype (vibrating insole) using inputs from broad literature, research team, and Pugh's design approach. The prototype's operation and function were successfully simulated during a teaching session in the classroom, and prototype had showed an early promise to improve the comfort and posture of school teachers.

The findings of this study are relevant since the prototype addresses a vital demand for ergonomic solutions in educational settings. By combining multiple research inputs and employing a structured design approach, this work not only improves the subject of wearable comfort solutions, but also provides a practical tool that might improve teachers' daily tasks. The prototype's preliminary success implies a possibility for larger use and future development, emphasizing the significance of ongoing study and refining.

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