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Anthropometric Design and Ergonomic Posture Assessment based on Intelligent Algorithms for Seated Work

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Abstract

Anthropometric Design and Ergonomic Posture Assessment based on Intelligent Algorithms for Seated Work

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Today, sedentary work is very common. Therefore, maintaining good posture while sitting is very important to prevent the occurrence of musculoskeletal disorders and declining performance. In particular, managing the sitting posture of children is very important as musculoskeletal disorders in childhood affect physical development and poorly postural habits formed in childhood are difficult to correct later.

Many factors have been identified that contribute to the adoption of a poor working posture. Among them is the use of anthropometrically mismatched workstation. School is the place where children spend a lot of time in a seated position, so school furniture must be designed carefully. In Korea, the heights of the desks and chairs at primary schools can be discreetly adjusted to one of seven levels as regulated by the Korean Industrial Standard for Student's Desk and Chair (KSG-2010). However, this standard was established long ago; thus, the height systems of present desks and chairs is inappropriate for Korean children of the current generation. In addition, even if the height levels accommodate children of all

heights, the accommodation level in real situation might be lower since some children would select inappropriate height level.

On the other hand, anthropometrically designed sitting furniture could be useless if the seated person has poor postural habits. To maintain a good posture, the formation of good postural habits must be encouraged through posture correction. However, long-term observation is required and posture correction is more effective when it is performed in real time. Thus, this study aimed to derive the following solutions for improving the sitting posture of children: a) Develop a new height system for school furniture; b) Develop new guidelines for selecting height levels of school furniture; c) Develop a novel sitting posture monitoring system; and d) Propose an integrated approach to managing poor working posture problems in various sedentary work settings.

In the first part of this study, anthropometric mismatch between height systems of school furniture and Korean children was analyzed. For the analysis, anthropometric data from 4014 Korean children were employed. The results showed that the height system of current desks could be matched with only half of the children due to the drawer attached beneath the desk. Almost all children could be matched by height to the current chairs, but some levels were redundant. To increase the matching degree, new height systems for the desks and chairs were developed using an algorithmic approach. We confirmed that the new height system for the desks can significantly increase the degree of match, while the new height system for the chairs comprising five levels can be matched to all children.

In the second part, we evaluated the anthropometric feasibility of the currently used guidelines for selecting the height level for Korean primary school furniture. We also examined the children's ability to select anthropometrically recommended desk and seat heights. In study 1, anthropometric data from 2005 Korean children were acquired and a mismatch analysis was performed under the assumption that the children were paired with the recommended height. In study 2, we conducted a desk and seat height selection experiment that included 36 children. The results of study 1 revealed that about three-quarters of children could be matched by following the guidelines. The results of study 2 showed that one-quarter of the children selected matching desk and seat heights by themselves. We developed new guidelines using classification algorithms based on the employed data in study 1 and confirmed that the new guidelines could significantly increase the degree of matching.

The third part addressed a study that aimed to develop a novel sitting posture monitoring system for children. In this study, a customized film-type pressure sensor was developed and pressure distribution data from nine sitting postures was collected from 7–12-year-old children. A convolutional neural network (CNN) was applied to classify the sitting postures and three experiments were conducted to evaluate the performance of the model in three applicable usage scenarios: usage by familiar identifiable users, familiar but unidentifiable users, and unfamiliar users. The results of our experiments revealed model accuracies of 99.66%, 99.40%, and 77.35%, respectively. Comparison revealed that leaning left and leaning right postures had high recall values while good posture and the leaning forward and crossed-legged postures had low recall values.

Finally, the research methods of the three studies in this thesis were summarized and generalized to solve poor working posture problems in various sitting settings. The problem sources of poor working posture were categorized by two aspects: use of anthropometrically mismatched workstation and poor postural habits. The first was subdivided into two cases: workstation size misdesign and the workers' choice of an incorrectly sized workstation. For the first problem source, a research process to evaluate the anthropometrical suitability of a workstation and the algorithmic method to derive optimal design sets were proposed. For the second source, a process to evaluate worker ability to select and guidelines for selecting anthropometrically suitable workstations and the development method of the guideline based on the machine learning algorithms was suggested. Finally, for the last source, a development procedure for a sitting posture monitoring system for real-time posture correction was developed.

This study confirmed that the currently used design and selection guidelines for school furniture require revision and that children had difficulty selecting the appropriate school furniture height by themselves. The new guidelines suggested in this study are expected to contribute to increasing numbers of children who use anthropometrically recommended school furniture. In addition, the developed sitting posture monitoring system is expected to help researchers observe the natural sitting behavior of children and contribute to the development of children's good postural habits by correcting poor posture in real time. Finally, it is expected that the research methods applied in this study could be utilized for solving poor working posture problems in various sedentary work settings. In particular, the algorithmic approach used to develop new height systems for desks and chairs can be applied to the development of size systems for workstations and other products. This study also confirmed that CNN is an excellent method for classifying posture when the pressure distribution data are used as input data.

Keywords: posture, working posture, workstation design, anthropometric design, children, posture classification, monitoring system, machine learning, deep learning

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Chapter 1

Introduction

1.1 Research background

Working posture greatly influences an individual's physical health and work efficiency. It was previously confirmed that inappropriate working posture for a long period of time could lead to musculoskeletal disorders and metabolic diseases (Burdorf and Sorock, 1997; Grandjean and Hünting, 1977). It is also widely known that inadequate working posture negatively affects the efficiency of task performance by restricting body balance, stability, and mobility (Gallagher, 2005). Accordingly, various work posture evaluation techniques such as RULA, REBA, and OWAS have been developed. These techniques have been widely used to evaluate working posture and identify and respond to risk factors that impede the good working posture (Hussain et al., 2016; Keester and Sommerich, 2017; Vignais et al., 2017; Wang et al., 2012).

Many factors affect working posture, including those attributed to the characteristics of the work environment, the work itself, and the worker (Kwon, 2016). Factors attributable to the work environment characteristics are those related to the surrounding environment that influence the worker physically and mentally while working, such as the work table; work tools; and workplace brightness, temperature, and humidity. Next, the factors attributed to the work characteristics are those that arise as a result of requiring a specific posture or movement to perform the work. Finally, factors attributed to worker characteristics mean the demographic, physical, and mental characteristics such as sex, age, body size, medical history, and work proficiency. Each factor has a distinctive feature according to its definition, but has a close relationship with each other. Therefore, to manage the work posture, a comprehensive approach to coping with all factors is needed.

Most workplaces provide a standardized work environment. Some workplaces are customizable; personalizing the work environment usually depends on the worker's subjective judgment. However, if the worker is exposed to a work environment that does not fit their anthropometric characteristics, an inappropriate working posture results. Therefore, to improve working posture, it is necessary to provide a workspace that is anthropometrically designed. One design solution is a provision of adjustability. The proper adjustment guidelines should be given to workers even if the workstation is adjustable since most people do not know how to adjust it to fit their body. In addition, even if the worker is working in a suitable work environment, it is necessary to encourage the development of good postural habits.

On the other hand, sedentary work has become increasingly more popular. Work that requires a sitting posture is generally static and does not induce a large physical burden on a specific site, but it has the potential to induce musculoskeletal diseases by maintaining and repeating an improper sitting posture over long periods of time (Christie et al., 1995; Pynt et al., 2001; Takemitsu et al., 1988). In particular, it can cause spinal diseases such as lumbar lordosis and kyphosis (Evcik and Yücel, 2003; Mandal, 1994; McKenzie and May, 1981). In addition, since excessive lumbar lordosis or kyphosis increases the disc pressure (Andersson, 1974), maintaining this posture for extended periods of time can lead to metabolic diseases resulting from limited nutritional support (Wilke et al., 1999).

It is very important to manage the sitting postures of children for several reasons. First, musculoskeletal disorders in childhood have a greater impact than those in adulthood. Spinal-related diseases are difficult to recover from; once they develop, they are likely to cause similar diseases (Troup et al., 1987). These diseases can be detrimental factors in the development of growing children (Tanner et al., 1976). Second, the postural habits formed in childhood likely persist in adulthood. Childhood is an important time for postural habits (Penha et al., 2005), which do not change easily once formed (Floyd and Ward, 1969; Yeats, 1997).

1.2 Study purpose

Among the various factors contributing to the adoption of a poor working posture, this study focused on the use of anthropometrically mismatched workstation and a worker's poor postural habits (Figure 1.1). As mentioned above, many studies have reported that these factors can cause an inappropriate working posture (De Wall et al., 1991; Delleman and Dul, 2002; Jakob et al., 2012; Jakob and Liebers, 2009; Kilroy and Dockrell, 2000; Li et al., 1995; Straker et al., 2008b; Wall et al., 1992). In particular, the problem source related to the use of a mismatched workstation was considered from two perspectives: in the first, a workstation's dimensions are improperly standardized; in the second, the workstation's dimensions are well designed but the workers cannot select the appropriate size. On the other hand, if workers have poor postural habits, they could adopt a poor working posture despite the use of an anthropometrically appropriate workstation. Thus, this study aimed to derive solutions to improve seated working posture. In particular, this study focused on these problems in children.

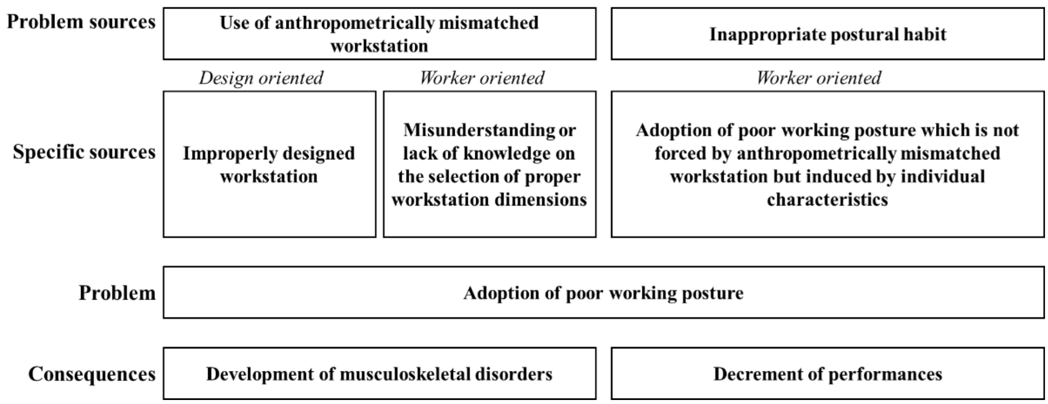


Figure 1.1 Problem sources focused upon in this study and their negative consequences related to poor working posture

In this study, the causes of children's poor sitting posture problems were defined from multiple perspectives in an attempt to effectively solve them. First, the anthropometric suitability of standard Korean school furniture was evaluated and a revised standard was suggested based on the algorithmic analysis results. Second, the study investigated the appropriateness of the currently used guideline for allocating school furniture to children and evaluated the ability of the children to select matching school furniture themselves. Moreover, new guidelines were suggested using machine learning algorithms. Third, a novel sitting posture monitoring system using pressure sensors was developed and its validity was tested. Finally, an integrated methodology for solving workspace design, workspace selection, and postural habit problems to induce safe working posture was developed based on the knowledge acquired from the studies described in Chapters 3, 4, and 5.

1.3 Organization of the thesis

This thesis covers the subjects described in Figure 1.2.

In Chapter 1, the study purpose is described according to the problems identified in the background research.

In Chapter 2, background knowledge is introduced to convey the basic concepts and ideas of this study and previous studies related to the research described in Chapters 3, 4, and 5 are reviewed.

In Chapter 3, the design of currently used sitting furniture for Korean primary schools is evaluated and revised according to anthropometric design principles. The research process is as follows. First, the design characteristics of the desks and chairs used in Korean elementary schools is investigated using related standards and field research. Second, data of anthropometric dimensions related to the design characteristics of desks and chairs are acquired. Third, the criteria to evaluate the anthropometric suitability of design characteristics of desks and chairs are established based on literature review findings. Fourth, it is evaluated whether the desks and chairs used in Korean elementary schools are well matched to the children using them. Finally, the problem of maximizing the anthropometric accommodation degree with a size system composed of a predetermined number of levels is solved using an algorithmic approach and the superiority of the proposed method is verified.

In Chapter 4, the currently used guideline and the children's ability to choose school furniture of anthropometrically recommendable heights are evaluated. The research process is as follows. First, to evaluate the suitability of the current guidelines, the children are allocated to one chair and desk set according to the guidelines and the percentage of children who were anthropometrically matched is calculated. At this time, the criteria to determine whether the assigned set and child are anthropometrically matched are the same as in the previous study. In addition, only the anthropometric data of the children who are anthropometrically matched desk and chair sizes are included in the analysis. Second, to examine the ability of the children to select an anthropometrically matchable desk and chair height, height adjustment experiments are conducted using an adjustable desk and chair. Finally, new guidelines are developed using machine learning algorithms.

In Chapter 5, a novel sitting posture monitoring system for children using pressure sensors is developed. The research process is as follows. First, the self-developed pressure sensor mat is inserted inside the seat and used to acquire posture data. This sensor mat was developed specifically to obtain pressure distribution data rather than actual pressure values, and the data can be transmitted via Bluetooth and stored in a self-developed measurement application. Second, the target postures and their operational and biomechanical definition are derived through a literature review and survey. Third, the posture data acquisition experiments are conducted. In the experiment, the pressure distribution data for the selected postures were obtained from children with various anthropometric characteristics. At this time, the data were acquired considering the fact that postural variance can exist even in the same posture. Finally, considering that the pressure distribution data can be expressed by a two-dimensional image, I developed a classification algorithm using a convolutional neural network and examined the classification's performance.

In Chapter 6, the major findings of the thesis are summarized. Additionally, an integrated approach to managing poor working posture problems in general sedentary work settings is proposed based on the knowledge acquired from the studies in Chapters 3, 4, and 5. Finally, the major findings of the thesis are summarized. the contributions and limitations of the thesis are discussed and further studies are suggested.

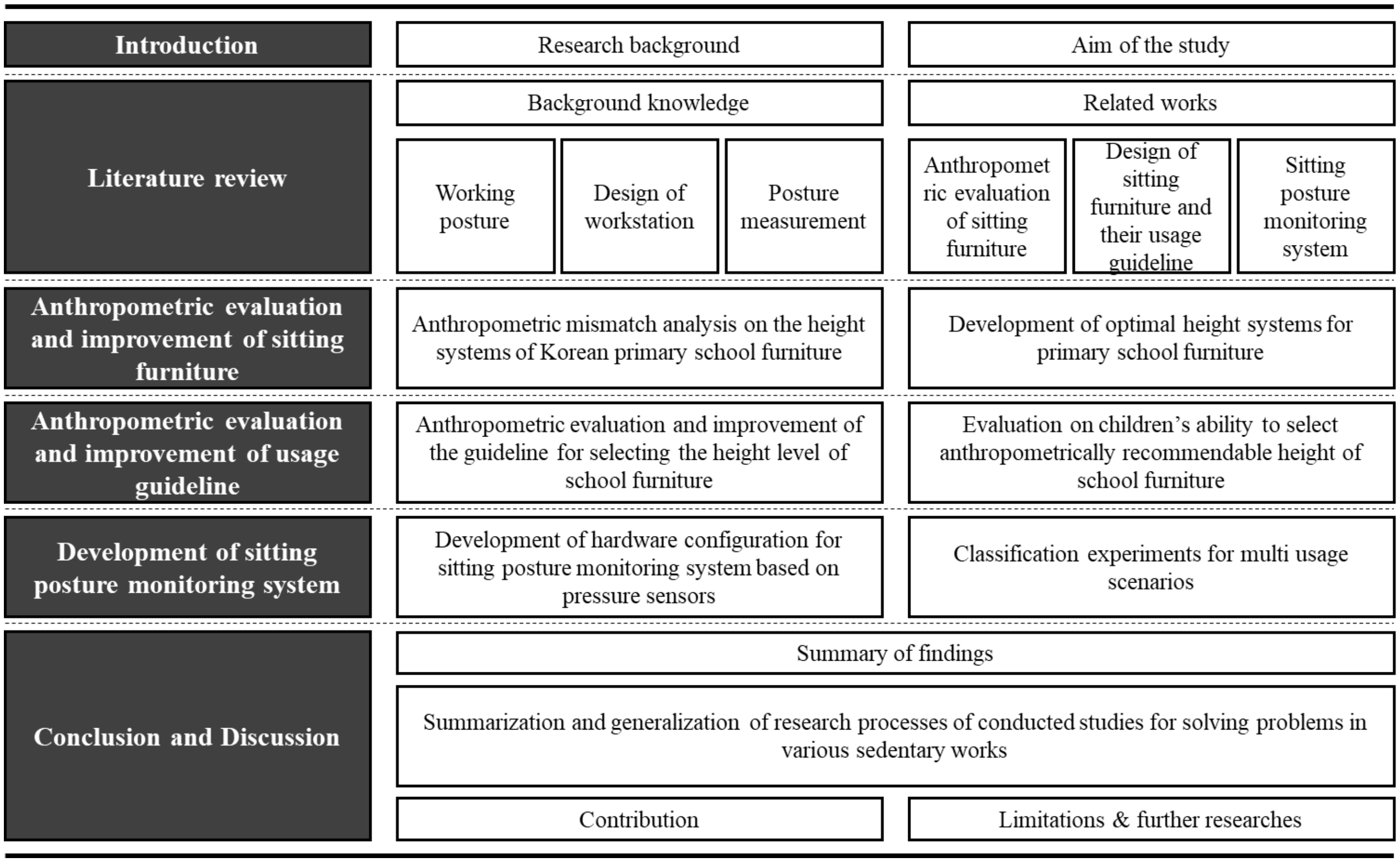


Figure 1.2 Organization of the thesis

Chapter 2

Literature review

2.1 Background knowledge

2.1.1 Working posture

2.1.1.1 Definition of posture

Posture is defined as an orientation of body parts in a space. Despite the simplicity of the definition of the word “posture,” it is very difficult to define it in engineering terms. From the engineering aspect, posture can be defined as the arrangement of the head, torso, and limbs. To my knowledge, a more detailed definition is unavailable. Rohmert and Mainzer (1986) defined posture as “quasistatic biomechanical alignment.” Similarly, Dempster (1955) described the human body as a massively linked system composed of joints and limbs. This linked system is very complex. Even in the same situation, there are various alternative postures. It is difficult to define the ultimate configuration in any situation since there are many joints in the human body and the degree of freedom is very high. Of course, there is an inherent limit to joint range of motion due to the body’s structure.

Dempster (1955) and Rohmert and Mainzer (1986) anatomically and kinematically analyzed posture and studied its relationship with human mechanical constraints. Measurable parameters of posture influenced the definition of posture. Rohmert and Mainzer (1986) proposed that posture can be explained geometrically in three ways: using the three-dimensional coordinate values of the individual joints, the angle between the axis of each body segment and the ground, and the relative angles between the axes of two adjacent body segments.

The most basic approach to designing a workplace or identifying the physiological and biomechanical effects of a task is to consider posture a configuration of the skeletal framework. Using this approach, the configuration can be expressed primarily as the relative positions of body parts and joints since the bones around the joints are rotated by the force exerted by the muscles; thus, the individual limbs or body segments move together organically. In this context, this approach can be very useful for assessing the appropriateness of posture. For example, in the case of visually demanding work, the appropriateness of posture can be judged by the position of the eyes and the head. For work in which hand reach is important, the appropriateness of the posture can be judged by the arm position. Finally, it could be determined whether work can lead to an increased prevalence of musculoskeletal disorders.

When analyzing posture, it is impractical to model the human body using a complete link-joint system that includes all joints and body parts. However, it is effective to analyze posture using a simplified system. To model the human body as a simple system, important joints and body parts must be selected and their degrees of freedom must be simply defined. This approach assumes that joint axes and fulcra are well defined. Unlike the wrist, elbow, and knee joints, complex joints, such as the shoulder or inaccessible joints of the spine can result in relatively inaccurate posture measurements when this assumption is applied. As long as noninvasive techniques are utilized, joint position is determined using reference points on the body's surface. In the case of relatively complicated joints, reference points can be defined as the approximate position of their center of rotation.

On the other hand, it cannot be said that the effects of posture are simply caused by changes in body part positions. Even with the same posture, the effects of posture can vary depending on the muscle strength required to adopt the posture and maintain balance, the duration that the posture has been maintained, and the previously assumed postures. Therefore, if posture is analyzed or evaluated using only a simple body outline or link diagram, the results may not be useful. Corlett (1983) argued that posture configuration and force and time records are required to correctly understand posture. For some tasks, to assess the effect of recovery on posture, it may be necessary to record how posture or force changes over time.

2.1.1.2 Effects of working posture

The importance of working posture has been emphasized persistently since long before. In the early 18th century, Ramazzini (1940) stated that an abnormal movement or unnatural posture during work resulted in negative effects on the craftsman. Thereafter, several researchers reported that workers can experience various musculoskeletal symptoms if they maintain a static posture for most of the time while working. It was also found that if these experiences lasted for long periods, they could lead to injury.

To maintain posture, some force must be exerted by muscles to withstand external forces acting on the body. Of these external forces, gravity is always present. Muscle is one tissue type that is very susceptible to persistent and static mechanical loads, while bone is another. These loads prevent the blood from being supplied smoothly to the muscles. When the intramuscular chemical balance is broken, waste accumulates in the muscle, resulting in muscle fatigue. Muscle fatigue can cause discomfort, and when there is a sense of urgency to resolve it, the posture eventually changes. Urgency arises when negative experiences are accumulated. Therefore, a well-designed workspace and work schedule should be provided so workers can assume a desired posture whenever they want to. Muscle fatigue can be recovered relatively easily by resting or changing posture. In particular, if a posture change involves stretching the tired muscles, the fatigue recedes more rapidly.

Nonetheless, pathological changes can occur in the muscle or soft tissue. These changes occur more gradually than suddenly, so it is difficult to pinpoint when they occur. Pain generally occurs after yielding to a sudden postural load; thus, even if one takes a break, the pain may not disappear. At this time, it is necessary to deal with the progression to physical injury or disease rather than discomfort. Typical diseases related to work are work-related upper limb disorders and repetitive strain injuries. These diseases can be induced when particular body parts, such as the back, neck, hands, wrists, and arms are used excessively and the soft tissues of the affected area are ruined. Excessive use means that there is a constant and static load, repetitive motion, exaggerated and excessive effort, or a combination thereof. Considering that an improper working posture can lead to excessive use of certain body parts and joints, improving the working posture is essential.

The working posture is even more important when performing tasks that require power. Andersson (1981) concluded that it is dangerous for workers to adopt a side-bending or twisted posture when lifting a heavy weight based on the epidemiological data on the back pain of industrial workers for 30 years and the results reported in several other countries. As a result, the working posture has a major effect on reducing worker stress and discomfort during work as well as improving performance and well-being. Corlett (1981) found a significant correlation between work efficiency and working posture. He confirmed that taking awkward postures during work would cause postural stress, fatigue, and pain, ultimately leading the workers to stop working until they recover from these negative consequences. He also argued that the pain rather than the inherent productivity could have a greater impact on the declines in efficiency and productivity. This assertion is supported by the fact that pain is also associated with mental stress, which can cause hormonal or metabolic changes, muscle tension, and behavior during tasks.

In summary, an improper working posture can be a serious risk factor for compromised health or safety during tasks that demand maintaining a fixed (unchanged) posture for relatively long periods of time or exerting force. In the first task type, inadequate working posture can lead to muscle fatigue and pain in the short term; these negative consequences result in cumulative physiological changes and injuries in the long term (Westgaard and Aarås, 1984). In the second task type, an inappropriate posture can increase the incidence of injury due to biomechanical stresses originating from external forces or muscle exertions. Finally, the working posture is significantly related to the comfort that people feel when working, so it can affect their work performance.

2.1.1.3 What is 'good working posture'?

The importance of working with good posture has been emphasized by many researchers. However, it is difficult to identify a clear definition of good working posture or a set of criteria for judging postural suitability. Definitions and standards for determining whether certain working posture are good or poor depend on empirical judgment of ergonomists and designers. To clarify them, a research-based field survey must be conducted. However, it is difficult to determine exactly what kind of posture the worker took due to the various environmental constraints, so the reliability of the result could be relatively low. Meanwhile, in laboratory studies, it is possible to measure the posture relatively accurately, but the experimental environment differs from the actual work site, so its applicability is limited.

Some studies have suggested a definition of good working posture, but they are limited to a specific part of the posture. For example, during a long-term visually demanding task, Grandjean (1988) suggested that there is a preferred viewing angle and Chaffin (1973) identified comfortable head and arm postures. Kee and Karwowski (2001) suggested the comfortable angle ranges of the main joints during sitting work. While these guidelines may be helpful to assess the suitability of the workplace design, there is limited ability to predict what posture people will choose when performing certain tasks.

Incidentally, a number of studies have examined what posture make people feel comfortable. Humans usually do not feel comfortable when joint angles are close to the limits of range of motion. Outside of the comfortable range, the level of discomfort gradually increases as the joint angle approaches the extremes. However, discomfort is heavily influenced by the duration of the posture and the overall body posture. Kee and Karwowski (2001) investigated how subjective judgments about comfort vary as the angles of the major joints change within the range of motion. As a result, they determined the degree to which each joint angle differs from the neutral state when comfort is significantly reduced. However, this study did not consider the interaction between adjacent joints connected to the same muscles. In addition, since the result is obtained by maintaining the posture for a relatively short period of time (60 s), it may be different from the result obtained by maintaining the posture for a longer period of time. Their findings can be used to assess the appropriateness of the working posture, but they are not the only criteria for good posture. In addition, comfortable postures can vary among tasks. Rebiffé et al. (1969) studied the comfortable posture of a driving task. He said that in the case of driving, a backward leaning posture is preferable to one that is thought to be comfortable in most work. This, of course, is established under the assumption that the seat back provides adequate support. In the case of a leg posture, a compromised posture is desirable so that the driver can apply the force to the pedal at any time but also for a long time.

2.1.1.4 Factors influencing working posture

In analyses of working posture, the factors that affect performance or the adoption of a certain posture should be considered (Pheasant and Haslegrave, 2005). At the least, the task's demands for vision, reaching with the hands or feet, manipulation, postural load, and biomechanical load should be considered. Obviously, the posture caused by these factors can vary depending on the size of the available area in the workspace or the presence of obstacles, which limit the worker's ability to maintain appropriate sight, reach, balance, or force. In addition, since these factors may conflict with each other in real-world situations, the actual working posture is formed in a compromised posture.

People generally assume a posture to minimize discomfort while working. However, some people adopt a posture to perform the task more quickly or easily due to the pressure of work performance, even if it may be dangerous.

Therefore, posture is determined by the functional requirements needed to perform a task and is constrained by the geometric relationship between human anthropometric characteristics and the design characteristics of the workspace. Functional requirements can affect different body parts differently. For instance, visual demands determine the position and orientation of the eye, thus affecting the head and neck posture. The requirements for the range of area for manipulation or the extent of force affect the hand and arm position. The choice of working posture is strongly influenced by the need to effectively perform a given task as well as minimize the muscle fatigue that occurs to achieve stability.

However, since the effects of each of these functional requirements on posture are not independent, it may be necessary to adopt a compromised posture, particularly of the head, neck, and arms. Kee and Karwowski (2001) found that tolerance of joint deviation is low in the order of the hip, lower back, and shoulder joints. Hsiao and Keyserling (1991) also concluded that people prefer to change the posture of the distal regions of the body rather than the torso. However, the posture that is finally adopted is dependent on the task's demands. For example, when work has a high visual demand, such as sewing, the worker frequently takes a high-load body posture (forward inclined posture) that makes it easy to perform the work. Another example is when people do lifting work, they usually assume a posture consisting of a straight waist and bent waist rather than bent knee. Kumar (1984) explained this tendency by the fact that people usually choose a movement that requires less energy.

2.1.2 Effects of workspace on worker

Occasionally, the workspace forces the worker to assume a specific posture that is difficult to change. The posture that a person assumes when performing a specific task is determined by the relationship between the dimensions of the body and those of various items in the workspace (for example, when using the standard kitchen, tall people will bend). The extent to which the posture is limited depends on the number and nature of the relationship between the person and the workspace. Some of these relationships are physical (seat, worktop, floor), while others are visual (viewing direction, location of displays).

If the dimensional match is not appropriate, it can cause the adoption of a poor working posture. A typical example of an improper posture is a situation in which the work surface is so low that the operator must bend his or her back or a situation in which the worker must squat down to see an item through a small window of a machine. Eventually, it can also have the negative consequences for human well-being. The consequences can be classified into short- and long-term results. In the short term, workers feel discomfort, which may interfere with the worker’s ability to do their job, thereby decreasing performance. Moreover, the risk of accidents is increased. If the postural load is severe, muscle fatigue increases over time; eventually, the worker becomes unable to continue the work.

2.1.3 Workspace design

2.1.3.1 General principles

Spilling et al. (1986) confirmed that it is possible to derive economic benefits by reducing the number of leaves of absence due to worker turnover or injury by improving the work environment. Ergonomists recognize that the industrial workspace design and layout affect the ability of workers to perform tasks. Therefore, when ergonomically designing or arranging a workspace, the goal is to help workers adopt a good posture. There are many suggestions to achieve the goal in published workspace design handbooks and guidelines. Corlett (1983) defined 10 principles for designing a workplace (Table 2.1). These principles are ordered by importance, so it is recommended that one follows the higher ranking principle when two or more principles conflict with each other in workplace design. However, because this is a general principle, low ranking principles may be more important in certain tasks. For example, in the task of simple repeatability, the tenth principle may be considered more important than other more highly ranked principles.

Table 2.1 Principles of workplace design (Corlett, 1983)

Order	Principle
1	The worker should be able to maintain an upright and forward facing posture during work.
2	Where vision is a requirement of the task, the necessary work points must be adequately visible with the head and trunk upright or with just the head inclined slightly forward.
3	All work activities should permit the worker to adopt-several different, but equally healthy and safe, postures without reducing capability to do the work.
4	Work should be arranged so that it may be done, at the worker's choice, in either a seated or standing position. When seated, the worker should **be** able to use the backrest of the chair at will, without necessitating a change of movements.
5	The weight of the body, when standing, should be carried equally on both feet, and foot pedals designed accordingly.

Table 2.1 (Continued)

Order	Principle
6	Work activities should be performed with the joints at about the mid-point of their range of movement. This applies particularly to the head, trunk and upper limbs.
7	Where muscular force has to be exerted it should be by the largest appropriate muscle groups available and in a direction co-linear with the limbs concerned.
8	Work should not be performed consistently at or above the level of the heart: even the occasional performance where force is exerted above heart level should be avoided. Where light hand work must be performed above heart level, rests for the upper arms are a requirement.
9	Where a force has to be exerted repeatedly, it should be possible to exert it with either of the arms, or either of the legs. without adjustment to the equipment.
10	Rest pauses should allow for all loads experienced at work, including environmental and informational loads, and the length of the work period between successive rest periods.

The general principles described above also can be used to design other products, equipment, or tools. The ISO standard 1473, Safety of Machinery (ISO, 2002), can be used as a basis for workspace design for standing and sitting work. As described in ISO 1473, when analyzing the task, it is essential to understand the nature and process of the work. It is important to identify the factors that may affect the worker, such as temporal demands, force requirements, and the need for communication or teamwork.

With an understanding of the requirements of the main task, it becomes possible to know where the physical interaction between the person and the workspace occurs, and these points must be carefully considered in the workspace design. The postures induced by the relationship between the workspace characteristics and the operator's body characteristics can be analyzed after the effects of the task requirements on the different body parts are considered.

However, it is necessary to investigate the effects of the workspace on workload, pain, and discomfort despite the workplace being designed with consideration of the factors that influence working posture. It is also important to analyze how these factors affect the recovery from the effects of the workspace. This enables the judgment of whether the working environment is suitable under actual working conditions.

During the workspace layout design process (determining the relative position of various elements in the workspace), some problems can be resolved by the anthropometric approach and some using common sense. Using common sense means following the four principles described in Table 2.2. This principle was first described by McCormick (1970). These principles can be applied to solve many design problems related to "what to put where." Examples of these problems are: how to arrange controls and displays within a panel, how to place furniture and appliances in a kitchen, how to arrange machines in a factory, and where to equip the facilities. In addition, the principles can also be applied to abstract design problems such as the way to sort information in a database. A link analysis is a technique that can be useful in these problems. Body movements between elements in the workspace or eye movements between the displays of the control panel can be analyzed by expressing movements as "links" on a workspace or panel. Since the frequency of the appearance of each link can be measured through observation, it is possible to apply McCormick's third principle using quantitative data (Kirwan and Ainsworth, 1992).

Table 2.2 Principles of rational workspace layout (McCormick, 1970)

Order	Principle	Description
1	Importance principle	The most important item should be in the most accessible location
2	Frequency of use principle	The most frequently used items should be in the most accessible locations
3	Function principle	Items with similar functions should be grouped together
4	Sequence of use principle	Items that are commonly used in sequence should be laid out in the same sequence

2.1.3.2 Anthropometric design

To design the workspace anthropometrically, it is necessary to establish a criterion to determine how well the workspace matches the user population. To do this, it is necessary to identify the user population and their characteristics (especially the distribution of anthropometric dimensions related to the relevant design dimensions) and understand how these properties can define the constraints that the workspace must satisfy.

Anthropometric constraints are the observable (preferably measurable) human characteristics that affect the artifact's design. A criterion is a standard for evaluating how suitable an artifact is for a user. There can be various criteria depending on the viewpoint, and these criteria can be hierarchically structured according to their importance. Generally, primary criteria are general and fundamental standards related to abstract concepts such as comfort, safety, efficiency, and aesthetics. To meet these criteria, related sub-criteria must be met. For example, in the case of a chair, comfort may be the most important and fundamental criterion for judging its design appropriateness. At this time, the length of the user's lower leg can act as a design constraint since if the chair is too high compared to the user's lower leg, excessive pressure may be applied to the lower thigh and cause discomfort. From this fact, to satisfy the primary criterion of comfort, the sub-criteria should be met in that the seat height should not be higher than the user's lower leg height. Therefore, in the case of a non-adjustable chair, it is reasonable to determine the height of the seat based on the 5th percentile value of the lower leg height in the user population. Such designed chairs can accommodate 95% of the user population.

It is extremely rare that only one criterion exists in real-world design problems. If multiple criteria exist, the relationships among the different criteria must be considered to derive the final design solution. Conflicts can occur between criteria at the same level in the pre-defined hierarchy of criteria according to importance; thus, trade-offs should be considered. For example, in the case of chair height, there is a conflict in the secondary criteria in that it should not be too high or too low. A criterion that the seat should not be too low has weak evidence. When one criterion is clear, but the other conflicting criterion is not, this can be a fuzzy situation. Even so, it could be reasonably inferred that a tall person may feel uncomfortable when sitting on a chair designed to accommodate a very small person. Therefore, seat height must be the proper height in accordance with the principle that the chair should provide comfort. In some cases, there may be a trade-off between comfort and efficiency or safety. A trade-off between comfort and safety is extremely rare, but if it does exist, it must be carefully considered which of the two criteria has priority.

Body dimensions used in an anthropometric design can be classified into two types according to their characteristics. The first is static dimensions measured in fixed and pre-defined postures. The second is functional (dynamic) dimensions. In contrast to static dimensions, functional dimensions are measured while people are moving or performing work tasks. Functional dimensions cannot be measured as accurately and consistently as static dimensions due to variations in the way the task is performed, even for the same worker. It is also relatively difficult to define data points for many functional dimensions. For example, in the case of maximum reach, the measured value may vary depending on how much the measured person wants to bend forward or can bend. Therefore, specific and consistent criteria must be applied to measure functional dimensions related to a specific task.

Designing an anthropometric workspace often requires some analysis or experimentation. There are three representative approaches: fitting trials, the method of limits, and body link diagrams. Fitting trials is the experiment-based method that determines the appropriateness of workspace dimensions based on the evaluation results of various value of dimensions from recruited subjects using mock-ups of adjustable workstations. When conducting a fitting trial, it is possible to let subjects perform all the work that should be performed or the most important task. The method of limits is a method of solving design problems using anthropometric data based on empirically derived solution through fitting trials. Another way to determine whether a workspace can accommodate people of various sizes is to analyze it using a body link diagram. This method involves an analysis based on the fact that people feel comfortable when performing tasks while the angles of main joints are in comfortable ranges. When using this method, link lengths can be approximated from the anthropometric data, while the postures in which people with various size feel comfort are expressed by the link diagrams. Using this diagram, it could be decided how workstations should be designed to accommodate people as many as possible. In recent years, computer simulation, automatic measurement technology, and image processing techniques have been developed. Using these techniques, design problems can be solved through simulation analysis using digital human models in a virtual environment.

2.1.3.3 Working height

One of the most important dimensions of a workspace is the work table height. Before discussing this, it is very important to distinguish between working height and table height. If the task requires the use of hand tools or other equipment, the working height may be significantly higher than the table height. In some cases, the working height may be lower than the table height. For example, if you are washing dishes in a typical kitchen, the task will be performed below the table's surface. Therefore, when determining the height of the desk, table, and bench, it is important to consider the working height.

When the work needs to be manipulated in the standing posture, the working height plays a very important factor in determining the worker's posture. If the working height is too high, the shoulders and upper arms will be elevated and the muscles in the shoulder (trapezius, deltoid, levator scapulae) will become tense and fatigued. When it is required to exert force downward to perform a task, if the working height is increased, the upper arm posture becomes mechanically unfavorable to exert force. This problem can be solved by lowering the working height. Using a lower working height, it is possible to minimize the load on the elbow and shoulder extensor muscles when applying a downward force. However, if the working height is too low, the neck and head will tilt forward, placing loads on the spine and back muscles. Therefore, a compromised height may provoke the working posture without causing excessive postural stress on the shoulders and dorsum, as well as excessive arm elevation. However, customized workstations are not widely used in industry. Therefore, the working height must be determined by considering the anthropometric characteristics of user population. Table 2.3 demonstrates the recommended working height according to task characteristics.

Table 2.3 Recommended working height by task characteristics (Pheasant and Haslegrave, 2005)

Task	Recommended working height
Manipulation tasks that require an appropriate amount of force or precision	50-100 mm below the elbow height
Precise manipulation tasks	50-100 mm above the elbow height (when appropriate wrist support is provided)
Tasks requires exerting significant forces	100-250 mm below the elbow height
Lifting task or handling task	Between the height of middle of thigh and the height of middle of chest (It is best to set a working height near the waist height.)
Tasks interacting with controller by hands (e.g. switches, levers, and etc.)	Between the elbow height and shoulder height

For some user populations, it is necessary to more carefully determine the working height. Paul et al. (1995) explored the working height needs of pregnant women performing manipulating work in a standing posture. Near the end of pregnancy, a woman's body shape is changed significantly compared to the pre-pregnant state in that the most protruding part of the abdomen becomes very close to the ideal working height. In addition, as the body's center of gravity moves forward, it becomes more difficult to reach distant objects; thus, the effective working area becomes smaller. As a result, they prefer a lower working height and tend to place the work point close to the edge of the workbench. However, the lower the height of the workbench, the more side effects may be occurred such as an excessively lowered back during work. Therefore, the worktable layout design for pregnant women should carefully consider the working posture and characteristics of the tasks performed. Some guidelines can also be applied to provide a suitable working height for people with disabilities (especially wheelchair users). The wheelchair seat is usually 470 mm above the ground. However, since most wheelchair users sit on a cushion, it is realistic to assume that the seat height is 490 mm (Goldsmith, 2000). He provided guidelines for working height in residential and office environments, while O Herlihy and Gaughran (2003) proposed a recommended working height in the workshop where hand tools such as a vice or drill are widely used. However, extrapolation is needed to apply the study results to the industry because the results of these studies derived by the data from teenagers.

2.1.4 Sitting work and posture

Sitting can be defined as supporting the body's weight on the ischial tuberosities of the pelvis and soft tissues around them (Schoberth, 2013). Depending on the chair and posture, part of the weight of the entire body can be distributed and supported on the floor, the backrest of the chair, and the armrest. Occasionally a desk or table supports the weight of the upper body. The sitting postures can be divided into anterior, middle, and posterior. This distinction is based on the body's center of gravity. According to the posture type, the areas of the chair supporting the body's weight differ, and the curvature of the lumbar spine is differentiated.

The advantages of a sitting position are that it can provide adequate stability for tasks with a high visual demand or requiring precise manipulation. Moreover, compared to a standing posture, less energy consumption, less stress on the joints in the legs, and decreased hydrostatic blood pressure within the leg can be expected. Biomechanical aspects must be considered in the design of a task that requires a sitting posture to leverage these benefits while reducing stress on the back, neck, shoulders, and upper limbs. When the sitting posture is biomechanically analyzed, an analysis of the spine is the most important, but the upper extremities must also be examined.

2.1.5 Effects of sitting furniture on sitter

The chair provides comfort and physiological satisfaction to the seated person to enable them to comfortably perform sedentary work or activities. Therefore, the design characteristics of the chair are among the major factors that should be considered very carefully in work planning. A very small change in the specific design or layout of the workspace can greatly change the posture required for the task. Since there is no unique ideal posture for performing a task, it is impossible to maintain a fixed posture for a significant period of time. Thus, although it may be contradictory to the fact that the chair should provide stable support to the seated person, it should be designed so that the seated person can freely change their posture. All humans respond to physiological signals, but they sometimes do not pay attention to the signals strong enough to change their posture. Branton (1969) found that train passengers unconsciously changed their sitting postures at intervals of 10–20 minutes. More precisely, they adopted a slumped posture for a while and eventually crossed their legs in that posture. A few minutes later, they assumed an upright posture with stretched out legs. They took these postures sequentially and repeatedly. He described this phenomenon as a chair ejecting a seated person slowly and repeatedly. In this case, this repeated postural circulation may alleviate the discomfort and deepening of physiological risk; their behavior did not appear to be driven by comfort. He thought that the postural behavior observed by passengers was due to excessive chair depth, the absence of lumbar support, and the slippery nature of the seat's material. Therefore, it is very important to design a chair anthropometrically to match the chair to the user. However, this is not the only solution. A chair design that fits the user's body characteristics is essential for comfort, but this is not the only consideration.

All chairs provoke discomfort when used for a long time, but some chairs can cause discomfort more quickly or cause greater discomfort for certain people. The characteristics of the chair include seat dimensions, seat angles, seat profile, stability and support, ingress/egress, and upholstery. These characteristics affect the postures that are taken naturally or intentionally when seated. Chair characteristics also affect the size of the area in which the body parts such as the torso, shoulder, head, and lower body are supported. If the body is not properly supported, the seated person must enlist muscle effort to maintain the sitting posture. If the seat profile does not match the seated person's body shape and size, unnecessary additional pressure may be applied to the soft tissues of the various body parts to withstand the person's weight. One of the major causes of discomfort is a backwardly tilted and hard front edge of the seat. When a person is seated on a chair with this characteristic, high pressure is applied to the lower thigh. This problem frequently occurs when the chair is too tall for the seated person. Muscle effort or pressure applied locally to a specific area of body causes negative physiological consequences such as muscle fatigue, blood flow blockages, and venous blood pooling (swelling) of the ankle or foot area in a relatively short amount of time. Thus, the basic criteria for good chairs have been suggested

(Vernon, 1924; Akerblom, 1949). The importance of these suggestions has been emphasized by several researchers (Andersson, 1987; Carlsöö, 1972; Engdahl, 1971; Floyd and Roberts, 1958; Grieco, 1986; Keegan, 1953; Kroemer and Robinette, 1969; Kroemer, 1971).

It is physiologically acceptable to sit for a (relatively) long time in a comfortable chair. Given that neural events that convey a feeling of discomfort may be considered a warning signal of imminent physiological tissue damage, it is hard to say that this assertion is completely wrong. Therefore, it can be deduced that there is no imminent damage when such a warning signal is absent. However, it is not so simple to prove this argument. Some claim that even though there is no sense of subjective discomfort, extensive and unnoticeable damage can occur due to poor sitting posture. It is also very difficult to refute this claim.

However, even if a person sits in a well-designed chair, long siting periods are not good for one's health. Sitting in a cramped condition for long periods of time can interfere with blood circulation, slow blood flow, cause edema in the lower limbs, and may lead to the onset of venous thrombosis. In the past, these problems were limited to people traveling overseas or traveling frequently, but in recent years, similar problems also arise for those who perform tasks that require sitting, such as computer work. Beasley et al. (2003) and Lee (2004) reported cases in which people who had no medical history passed out or died suddenly after sitting in front of the computer for an extended period of time (3–4 days). These cases are seen as leisure-related rather than work-related, but they are sufficient to raise awareness about sitting for long periods of time with limited movement. The risk of long-term sitting with an improper posture has been recognized for a long time. Recent studies have examined the potential risks associated with computer use such as eThrombosis. The researchers' opinions about good chair design have yet to reach consensus, but we know that chair design should not limit the sitting posture according to physiological evidence.

Comfort is also affected by the characteristics of the tasks or movements during sitting work. In particular, the characteristics of the task is as important as the chair's design characteristics (Eklund, 1986). These characteristics include task duration and visual, physical, and mental demands. The visual and physical demands of a task greatly impact the posture assumed to perform it. Depending on the task's demands, the parts of the body that are to be properly supported therein will vary; thus, the demands influence the design characteristics of the appropriate chair. For example, if a sitting person performs a complicated assembly task, a tilted backrest cannot be utilized effectively; in contrast, it can increase the worker's postural fatigue. If the person performs a task requiring force exertion, the chair must be firm and stable and the orientation of the seat's surface should be determined with consideration of the direction of the reaction force applied to the worker by the force exerted by the worker. Comfort can be influenced by the task's characteristics as well as the user's characteristics such as body dimensions, medical history, pain, and psychological state. In summary, chair comfort (or, more specifically, chair discomfort) is determined by the relationships between chair, user, and task characteristics.

However, the sitting posture depends not only on the chair's design, it is also influenced by the individual's postural habits and the task's characteristics. For example, anterior sitting postures are taken when small parts are being assembled. Meanwhile, posterior sitting postures are usually taken during video display terminal (VDT) tasks or break time.

2.1.6 Design considerations for sitting furniture

As discussed above, it is clear that it is desirable for workers to regularly change their posture, even for sitting work. If one must work in a fixed sitting position (as is often the case), the worker can have negative physiological experiences due to intensive pressure on a particular body part. In addition, like in a standing position, negative consequences caused by muscular load could also be experienced in a sitting position. Corlett (1983) suggested a simple guideline to refer to when designing a workspace for sitting.

First, sitting workers should be able to sit in various postures. Several office chairs have been designed with these guidelines in mind. Some tasks in the industry require a sit–stand workstation. The working surface of these tasks is given the appropriate height for standing work and a tall chair is usually provided. On the other hand, it may not always be possible to encourage workers performing most sitting tasks to get up and move around for a while when they are at work. In such cases, it may be possible to solve the problem by changing work schedules or rotating jobs rather than improving the workspace layout.

Second, the head and neck should not be excessively inclined forward. Tilting the head and torso forward usually occurs when the work surface is too low to meet the visual demands required for the task. For this type of task, it is often possible to prevent this improper posture by raising the work surface, improving visibility, or tilting the work surface (De Wall et al., 1991). ISO standard 14738 (ISO, 2002) recommends tilting the work surface 15 degrees for tasks requiring high visibility or precision.

Third, one must avoid elevating the upper extremity too much. If the work surface is too high or the seat is too low, the worker’s arm will usually be elevated. The heights of the work surface and the seat should be properly adjusted so that the worker can work with a relaxed arm posture. Arm supports should be provided when a worker must perform while using an elevated arm posture (mainly due to visual demands). Failure to do so can result in a severe load on the shoulder muscles, while blood circulation problems can also occur if tasks are to be performed at a higher position than the heart. The upper limit of work surface height for the manipulation task is that approximately halfway between the elbow and the shoulder. When the work surface is too high and the arms are elevated, it also affects the lower arm and hand postures.

Fourth, a twisted or asymmetrical posture should be avoided. These postures are usually adopted when looking back is needed due to the nature of the job or misplacement of materials, operating devices, or cargo boxes. These situations often arise if the workspace was created by designers who lack knowledge of the task's characteristics or the relationship between the elements. If a workbench must be located at the worker's side, he or she should be encouraged to perform the job by shifting sideways rather than bending to the side or twisting at the waist. In the case of sitting work, it is possible to avoid assuming an improper posture by providing a swivel chair unless force is required to perform the task.

Fifth, when a worker performs a task, the range of motion of the joints should be prevented from approaching the limit repeatedly or for a long duration. These guidelines are also important for the shoulder, neck, and other joints as well as for the body parts involved in most tasks such as the anterior arms, wrists, and hands. Of course, there can be other causes of the adoption of these inadequate postures.

Sixth, the chair provided should have a suitable backrest. If a proper backrest is not provided, tension may occur in the muscles of the neck, shoulders, and back. For some tasks, it may be better not to use the backrest while working and save it for rest times.

And finally, in the case of work requiring the exertion of force, each body part should be able to achieve positions that exert the greatest power. In this position, the least muscular efforts can produce the required forces, thus minimizing the stress on the body and reducing the risk of injury. This guideline becomes more important when the required forces to perform the task increase. Improper postures are mechanically unfavorable for exerting the force, so the worker's physical load is rapidly increased.

Before designing a workspace for a sitting job, it is important to decide whether the job is suitable for a sitting or standing position (ideally, one alternates between the two positions). The cases better to work in a sitting position are when it is necessary to perform a task over a long period of time, the whole body must be very stable, or a foot controller is required. Meanwhile, the standing position is recommended when heavy or bulky objects must be handled or frequent movements are required.

2.1.7 Anthropometric design of sitting furniture

2.1.7.1 General guidelines

The experts' opinions and users' needs of chairs are very diverse; accordingly, various types of chairs have been developed. For example, the designs of driving seats, office chairs, and machine shop stools are quite different from each other. However, all seats should be adjustable so that they be well matched to the worker's body dimensions just like other equipment in the workspace. Thus, several studies have suggested how seats should be designed, although their findings varied slightly among countries. This is not surprising considering that anthropometric characteristics vary among countries. A chair's dimensions requiring careful considerations are typically height, width (breadth), length, and pan slope. Of course, seat shape, friction, softness, adjustability, and climatic comfort should also be considered.

In the design of a table for sitting work, the most important dimensions are the height of the underneath surface for leg clearance, the height of the top of the table to determine the position of the hand and forearm, and the slope of the table surface, which affects the visual performance. The table surface must be spacious enough to accommodate the materials and tools needed for the work and have adequate roughness to prevent the objects from slipping from a tilted work space. It is not desirable to provide the same table height for all jobs since the size of the object or tool being handled and the placement of the workspace differ among jobs. Moreover, the table height must be adjustable to effectively accommodate workers with different jobs or anthropometric characteristics.

2.1.7.2 Sitting furniture height

The recommended chair height is 3–5 cm lower than the popliteal height when the person is sitting on the chair and the lower legs are positioned perpendicular to the ground. This is the recommended height when the seat is tilted back slightly. Bendix (1987) proposed a recommended chair height when the seat is tiltable or tilted forward. The slope of the seat is very important because the relationship between the seat and the table can be newly established. If the seat is not tiltable forward, the sitter may feel pressure at the lower thigh when the seat is too high. When the chair height cannot be adjusted, a footrest can be provided to compensate for it.

If the seat height exceeds the popliteal height, the seated person will feel pressure beneath the thigh. As a result, the blood circulation to the lower extremities decreases and numbness and foot swelling may occur, causing discomfort. However, the lower the seat height, the more likely that the seated person will bend at the waist to make the angle between the thigh and the waist acute. In addition, sitting on and arising from the chair becomes more difficult due to the incremental weight shifting distance and need for greater leg room. Thus, the optimal seat height for achieving various goals is generally similar to the popliteal height. In situations in which it is impossible to satisfy this recommendation, the seat height should be lower than the popliteal height. Therefore, for various reasons, it may be considered the best compromise to set the height of the chair to the 5th percentile value of the popliteal height of a woman. If it is necessary to set the seat height higher (if the seat height must be matched to the table height or leg room is limited), the negative effects of the high seat height could be relieved by shortening the sitting time or rounding the front edge of the seat. However, seat height should be prioritized over table height.

The first decision during table design is the height beneath the table to ensure adequate leg clearance. If the leg clearance is insufficient, even if the sitter initially adjusted the seat height properly, he or she may be forced to lower the seat height again and adopt an improper posture such as putting the legs to the side and twisting at the waist. This posture can cause various musculoskeletal problems. It is suggested that the table or workbench thickness not exceed 7–8 cm to ensure sufficient leg clearance and that the table height be adjustable.

The criteria for judging whether the relevant table dimensions are appropriate based on anthropometric dimensions are provided in a similar form, but the recommended dimensions differ slightly among countries. As mentioned earlier, table height should be adjusted based on the elbow's position while the worker sits on a chair with an appropriate seat height. It is generally known that the height of a table or workbench should be adjusted to 3–4 cm above the elbow's height during sitting (Bendix, 1987). If the table's height is higher than this, the chair's height should be increased and a footrest should be provided if necessary. If the height of the table or the working height is too low or the working point is too far from the worker, the waist will be bend and lumbar lordosis may occur. If this posture is maintained over an extended period, the loads on the back and neck would be significant. The visual demands of a task also affect various aspects of sitting posture (Li and Haslegrave, 1999). It should be noted again that the height of the working surface is not the same as the table height. For example, for computer work, the height of the working surface is the height of the keyboard. A tilted work surface helps improve the neck and back postures but can affect working performance. Bendix (1987) asserted that tilting the work surface toward the worker helps prevent excessive flexion of the neck to ensure visibility and maintain a comfortable sitting posture. According to the results of this study, the slope of the working surface had a greater effect on lumbar posture than did the slope of the seat.

2.1.7.3 Other dimensions of sitting furniture

If the seat depth is longer than the buttock–popliteal length (the 5th percentile of a woman is 435 mm), excessive pressure on the calves is unavoidable for supporting the back, so the back is difficult to support by the backrest. Furthermore, as seat depth increases, arising from a chair becomes increasingly more difficult. It is challenging to determine the minimum acceptable seat depth. In some cases, a seat depth of at least 300 mm may be required to satisfactorily support the ischial tuberosities. However, tall people may feel discomfort with a shallow seat depth.

Seat width should be designed to provide a minimum clearance width of 25 mm on both sides of the hips to ensure proper support while sitting. Therefore, 385 mm is suitable. However, if armrests are present or the edges of the seat are not flat, the seat should be able to provide adequate space for even the largest person among a user population. Based on unclothed women, the 95th percentile of hip width is 435 mm. In real life, seat width should be at least 500 mm since workers are dressed and require the freedom to change sitting positions.

The higher the backrest, the more effectively the load of the torso can be supported. Ideally, the higher the backrest the better; however, in some situations, it may be more important to meet the task demands, such as by not restricting shoulder movement. Therefore, it is necessary to determine whether a low, medium, or high backrest is best for work.

2.1.8 Evaluation of sitting furniture

According to the above-mentioned discussion, it is obvious that anthropometric considerations are required in chair design. However, anthropometric criteria cannot be the only criteria in determining whether a chair is suitable for work or leisure. Each task may require a different chair and sitting posture, which may result in different physiological and biomechanical consequences. Seat suitability is influenced by all these factors.

Physiologically, comfort is still not a clearly defined concept, but many existing studies have defined it as the nonexistence of discomfort (Floyd and Roberts, 1958; Wachsler and Learner, 1960) because the nerve endings do not convey a positive sensation. Comfort can be influenced by many other factors, but it can be defined as the state of mind that is caused by the absence of unpleasant sensations that are felt in the body. Recent studies have shown that the perception of comfort and discomfort about seats is independent and influenced by different factors; therefore, comfort and discomfort cannot be expressed on the same scale (Helander and Zhang, 1997; Zhang et al., 1996). According to these studies, discomfort is associated with fatigue, low back pain, excessive pressure, edema of the legs, pain or stiffness in the neck and shoulders, numbness, and bitterness. These effects tend to increase with sitting time. In contrast, comfort is related to aesthetics, feelings of relaxation and well-being, the absence of discomfort, or feelings of neutrality. Webster's dictionary defines comfort as a satisfying and pleasant experience. Slater (1985), in more detail, defined comfort as a state of physiological, psychological, and physical harmony between humans and the environment. In this sense, it can be inferred that task characteristics and the human emotional state are very important factors in determining comfort. Therefore, comfort cannot be treated as an absence of discomfort but rather as the complex feeling formed by various factors. Therefore, the comfort–discomfort rating scales can no longer be considered one-dimensional. However, humans cannot feel comfort when feeling discomfort in any part of the body.

Systematic assessment techniques used to evaluate seats include empirical studies, biomechanical analysis (using force, pressure, or spinal shrinkage measurements), electromyography, and subjective assessments using psychophysical techniques. The discomfort felt in each body part can be assessed by choosing the affected part using a body map and rating the degree of discomfort and pain (Borg et al., 1981; Corlett and Bishop, 1976). Comfort can be evaluated similarly. Shackel et al. (1969) developed the General Comfort Rating, which is used to evaluate seats. This technique is widely used with the Chair Feature Checklist (a set of nine rating scales) developed by Drury and Coury (1982) to identify the seat dimensions that contribute to discomfort. Helander and Zhang (1997) developed the Chair Evaluation Checklist, which can be used to independently measure comfort and discomfort. According to their field study, discomfort is greatly influenced by sitting behavior and duration. However, discomfort is relatively less affected by the seat's shape unless the seat is seriously ill-designed. Subjective assessments have limited objectivity and reliability; as a supplementary measure, they are subjected to evaluations by experts (Jones, 1969) and people with low back pain (Hall, 1972). Despite a number of studies on chair comfort, opinions about which methods are accurate and reliable have not reached an agreement (Corlett, 1989; Drury and Coury, 1982; Shackel et al., 1969; Zhang et al., 1996).

To evaluate a chair's comfort (or discomfort), it is necessary to sit in it for a certain period of time. Evaluating comfort using one's first feeling (showroom appeal) can lead to false evaluation results. Researchers have different opinions about how long they should sit to properly evaluate chair comfort. While Wachsler and Learner (1960) concluded that a 5-minute evaluation was as reliable as a 4-hour evaluation, Barkla (1964) argued that a minimum duration of 30 minutes is required. Fernandez and Poonawala (1998) found that the evaluation of a chair's comfort took 3 hours to stabilize, but Helander and Zhang (1997) asserted that relative comparisons between the chairs could be performed in a few minutes.

Although opinions on evaluation time are divided, sitting for 5–30 minutes is recommended to ensure reliable evaluation results.

Fidgeting frequency also can be used as a simple indicator of chair comfort. When people sit in a less comfortable chair, they fidget more. Fidgeting is generally considered the body's defense mechanism against postural stress. This mechanism works at the subconscious level. In other words, fidgeting generally occurs before one recognizes the feeling of discomfort. Of course, other factors are involved in fidgeting. Some people fidget more than others, while others fidget when they feel bored. This tendency may be attributed to the fact that when a person is focusing on something, mental activity blocks the sensory stimuli that cause fidgeting (or concentration may increase the discomfort threshold). This hypothesis is consistent with the theory about the principle of pain (Melzack and Wall, 1983).

Taken together, these findings suggest that comfort is a rather difficult concept to apply in a chair evaluation. Although there are a variety of evaluation methods, one of the representative and reasonable approaches is to first evaluate the chair based on collecting anthropometric and physiological data, conducting a fitting trial, and finally making a judgment based on the results. Comfort can vary among tasks, so the results evaluated in the lab may not be as meaningful as the results of careful field evaluations.

2.1.9 Measurement and analysis of posture

The posture measurement and analysis method depends on which parameters are used to define posture. Various posture recording techniques have been devised (e.g. Corlett, 1990). Winter and Milsum (1979) proposed a procedure for analyzing posture using motion capture data, while Colombini et al. (1985) proposed a method for analyzing the working posture based on descriptively defined working postures. Typical posture measurement techniques provide the following posture parameters:

(a) Joint location: Unless invasive methods such as X-ray, ultrasound, or magnetic resonance imaging are used, each joint's position is approximated to the location of a touchable point on the skin's surface. Using optoelectronic, acoustic, and electromagnetic sensors, it is possible to accurately and automatically record the three-dimensional coordinates of each joint in space.

(b) Joint angle

(c) Relative position of each body part from the reference position (reference posture). The posture analysis method using this parameter is called posture targeting (Corlett et al., 1979).

(d) Posture and movement notation (Hutchinson and Anderson, 1970; Kember, 1976)

(e) Type of posture (e.g. OWAS (Karhu et al., 1977) for whole-body posture as well as a hand and arm posture measurement system (Armstrong, 1986)): These coding systems are useful for identifying inadequate postures.

(f) Body outlines (photographs, video recordings, sketches)

These parameters are incompatible with each other, so the parameter should be carefully chosen depending on the purpose of the posture measurement. For example, anatomically relevant joint angles are useful when evaluating strength capability or endurance. This is because the torque strength applied to the joints according to the joint angle can be calculated. However, if there is no relative position data for each joint measured in the same reference frame, there is a limit the usefulness of a full biomechanical analysis of musculoskeletal loading using only joint angle data. In the case of three-dimensional coordinate recordings of each joint, it is possible to define the body structure relatively completely and transform into other proposed posture parameters. However, obtaining such data requires complex and expensive measuring equipment and is time consuming.

2.2 Related works

2.2.1 Anthropometric design or evaluation of school furniture

The use of anthropometric data to design school furniture requires a simultaneous evaluation of pedagogical, financial, anatomical, and ergonomic principles. One of the most frequently used design strategies based on anthropometric data is identifying the design solution that can maximize the matching rate between anthropometric criteria and target user populations. Many studies have expressed the criteria as “mismatch equations” that define the acceptable range of anthropometric dimensions. The mismatch equations are based on the ergonomic principles that have been developed by many researchers. It is difficult to say that an anthropometric design using mismatch equations is superior and faultless. However, it has meaning in design problem solving processes because some consistent design guidelines (or rules) are essential in determining the size of various products. In addition, these equations do not vary by ethnicity or age. For that reason, many studies have utilized mismatch equations to design school furniture (Afzan et al., 2012; Agha, 2010; Castellucci et al., 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006; Batistão et al., 2012; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcells et al., 1999; Ramadan, 2011; Van Niekerk et al., 2013).

Studies related to anthropometric suitability assessments of school furniture have been conducted in Greece (Panagiotopoulou et al., 2004), Gaza (Agha, 2010), Chile (Castellucci et al., 2010), Saudi Arabia (Ramadan, 2011), United Arab Emirates (Bendak et al., 2013), and Indonesia (Yanto et al., 2017) (Table 2.4). The results of these studies vary due to the differences in anthropometric characteristics of the target populations and the furniture’s design characteristics, but all studies found that furniture dimensions have many problems. All studies reported serious mismatch problems regarding seat and desk height.

All studies had similar research procedures. First, they selected the design characteristics of school furniture that requires a suitability assessment. Second, the selected furniture dimensions and related body dimensions of the children are measured. Third, they define the appropriate range of furniture dimensions based on the anthropometric guidelines. Finally, they evaluate the anthropometric suitability of the furniture based on the calculated ratio of children who cannot be matched to the currently used furniture. Table 2.5 and Table 2.6 summarize the anthropometrically recommended ranges of chair and desk dimensions used in the previous studies.

Table 2.4 A review on previous studies related to anthropometric evaluation of school furniture

Reference	Region	Age	Number of subjects	Measured anthropometric dimension	Investigated school furniture dimensions
Panagiotopoulou et al. (2004)	Greece	7 - 12	180 (90/90)	stature elbow height, sitting shoulder height, sitting upper arm length knee height, sitting popliteal height buttock–popliteal length	seat height seat depth seat slope desk height desk clearance desk slope
Agha (2010)	Gaza strip	6 -11	600	elbow height, sitting shoulder height, sitting knee height, sitting popliteal height buttock–popliteal length	seat height seat depth backrest height desk height under-surface of desk height

Table 2.4 (Continued)

Reference	Region	Age	Number of subjects	Measured anthropometric dimension	Investigated school furniture dimensions
Castellucci et al. (2010)	Chile	12 - 14	195 (94/101)	stature popliteal height buttock-popliteal length elbow height, sitting Hip width, sitting thigh thickness subscapular height	seat height seat depth seat width seat to desk clearance seat to desk height upper edge of backrest desk width desk depth
Ramadan (2011)	Saudi Arabia	6 - 13	124	stature shoulder height, sitting elbow height, sitting knee height, sitting popliteal height buttock-popliteal length	seat height desk height
Bendak et al. (2013)	Arab Emirates	13	200 (100/100)	stature elbow height, sitting thigh thickness popliteal height buttock–popliteal length hip width subscapular height	desk width desk depth seat width seat depth seat height seat to desk height seat to desk clearance upper edge of backrest
Yanto et al. (2017)	Indonesia	6 - 12	1146 (584/562)	stature shoulder height, sitting elbow height, sitting popliteal height buttock-popliteal length knee height, sitting hip breadth	seat height seat depth seat width backrest height desk height underneath desk height

Table 2.5 Anthropometrically recommended ranges for school chair dimensions suggested in previous studies

Dimension	Recommended range	References
SH	$(PH + SC)\cos 30° \leq SH \leq (PH + SC)\cos 5°$	Afzan et al., 2012; Agha, 2010; Castellucci et al., 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006
	$0.88\ PH \leq SH \leq 0.95\ PH$	Batistao et al., 2012; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcells et al., 1999; Ramadan, 2011; van Niekerk et al., 2013
	$0.80\ PH \leq SH \leq 0.99\ PH$	Ramadan, 2011
SD	$0.80\ BPL \leq SD \leq 0.95\ BPL$	Afzan et al., 2012; Agha, 2010; Batistao et al., 2012; Brewer et al., 2009; Castellucci et al., 2010; Chung and Wong, 2007; Cotton et al., 2002; Dianat et al., 2013; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcells et al., 1999; van Niekerk et al., 2013
	$0.80\ BPL \leq SD \leq 0.99\ BPL$	Gouvali and Boudolos, 2006
SW	$HW < SW$	Afzan et al., 2012; Castellucci et al., 2010
	$1.1\ HW \leq SW \leq 1.3\ HW$	Dianat et al., 2013; Gouvali and Boudolos, 2006; van Niekerk et al., 2013
UEB	$0.6\ SHH \leq UEB \leq 0.8\ \mathrm{SHH}$	Afzan et al., 2012; Agha, 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006
	$SUH \geq UEB$	Castellucci et al., 2010

Note. Furniture dimensions – SH: seat height; SD: seat depth; SW: seat width; UEB: upper edge of backrest

Anthropometric dimensions – SHH: shoulder height, sitting; PH: popliteal height; BPL: buttock–popliteal length; HW: hip width; SUH: subscapular height; SC: shoe clearance

Table 2.6 Anthropometrically recommended ranges for school desk dimensions suggested in previous studies

Dimension	Recommended range	References
UDH or SDC	$KH + SC + 2 < UDH$	Agha, 2010
	$KH + 2 < UDH$	Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Panagiotopoulou et al., 2004; Parcells et al., 1999
	$TT + 2 < SDC$	Castellucci et al., 2010
	$(KH + SC) + 2 \leq UDH \leq [(PH + SC)\cos 5°] + (0.8517\ EHS) + (0.1483\ SHH) - 4$	Gouvali and Boudolos, 2006
	$PH + 20 < UDH$	Jayaratne and Fernando, 2009; Jayaratne, 2012
DH or SDH	$EHS + [(PH + SC)\cos 30°] \leq DH \leq [(PH + SC)\cos 5°] + 0.8517\ EHS + 0.1483\ SHH$	Afzan et al., 2012; Agha, 2010; Gouvali and Boudolos, 2006
	$EHS \leq SDH \leq 0.8517\ EHS + 0.1483\ SHH$	Batistao et al., 2012; Brewer et al., 2009
	$EHS \leq SDH \leq EHS + 5$	Castellucci et al., 2010; Dianat et al., 2013
	$(SH + 0.8517\ EHS + 0.1483\ SHH) - DH < 0$	Chung and Wong, 2007
	$SH + EHS \leq DH \leq SH + 0.8517\ EHS + 0.1483\ SH$	Panagiotopoulou et al., 2004; Ramadan, 2011

Note. Furniture dimensions – SH: seat height; UDH: under desk height; SDC: seat to desk clearance; DH: desk height; SDH: seat to desk height
Anthropometric dimensions – EHS: elbow height, sitting; SHH: shoulder height, sitting; KH: knee height, sitting; PH: popliteal height; TH: thigh thickness; SC: shoe clearance

Most studies surveyed specific schools in a specific area. Thus, it is doubtful that the results would be consistent if the survey were administered to children in a wider region or country. In addition, many studies that have not attempted to improve the design. In some of the studies that aimed to improve the design, the reliability of the improvement results may not be sufficiently guaranteed because improved designs were derived using descriptive statistics of body dimensions (e.g., 5th percentile, average, 95th percentile). Moreover, to the author's best knowledge, no quantitative evaluations have been performed of Korean school furniture.

2.2.2 Development of size recommendation system

Many studies anthropometrically assessed school furniture and reported that a significant number of children had appropriate school furniture but did not use it. Some studies have attempted to develop a guideline for allocating anthropometrically matchable furniture using representative body dimensions (Castellucci et al., 2015a; Cho, 1994; Evans et al., 1988; Hibaru and Watanabe, 1994; Molenbroek et al., 2003; Tuttle et al., 2007). These studies concluded that stature and popliteal height are the most important variables for size matching (Table 2.7). However, these studies lacked validity regarding how many children can be matched accurately when the suggested guideline is used for larger number of children.

Table 2.7 A review on previous studies focusing the allocation of anthropometrically recommended size of school furniture

References	Type of workstation	Considered dimension	Selected (Expected) variables for size allocation
Tuttle et al. (2007)	school furniture	seat height	popliteal height
Castellucci et al. (2015a)	school furniture	seat height seat depth seat to desk height seat width upper edge of backrest seat to desk clearance	stature popliteal height
Cho (1994)	school furniture	desk height	sitting height
Hibaru and Watanabe (1994)	school furniture	17 dimensions for chair	popliteal height
Molenbroek et al. (2003)	school furniture	seat height seat depth to back support height frontal point back support height lowest point back support height highest point back support seat width vertical span below table horizontal knee space horizontal clearance below the table table height	stature popliteal height
Evans et al. (1988)	school furniture	14 dimensions for table and chair	stature age

2.2.3 Development of posture monitoring system using pressure sensors

To non-invasively observe a user's posture and help individuals develop the appropriate postural behavior, many studies have been performed to predict user posture by attaching pressure sensors to a chair's seat or backrest (Chenu et al., 2009; Meyer et al., 2010; Tan et al., 2001; Xu et al., 2013; Zemp et al., 2016b).

Table 2.8 summarizes the major previous studies, which collected pressure distribution data using self-developed sensor arrays or commercial products attached to the seat or backrest. The target postures varied among studies but commonly include upright, leaning forward, leaning backward, leaning left, leaning right, and crossed-leg. Algorithms used for classification varied. However, in previous studies, the definition of posture was unclear and the posture data were acquired for adults only. More detailed information of all related studies including the proceedings is shown in Table 2.9-12.

Table 2.8 A review on previous studies aimed to classify the postures using pressure sensors

References	Subjects	Number of subjects	Number of postures	Sensor configuration	Classification algorithms	Overall accuracy
Tan et al. (2001)	Adults	30	10	Seatpans (42*48), Backrest (42*48)	PCA-Based Classifier	79%
Chenu et al. (2009)	Adults	12	9	Seatpans (32*32)	rule-based classifier	No info

Table 2.8 (Continued)

References	Subjects	Number of subjects	Number of postures	Sensor configuration	Classification algorithms	Overall accuracy
Meyer et al. (2010)	No info	9	16	Seatpans (240), Backrest (1)	Naive Bayes classifier	81%
Xu et al. (2013)	No info	25	7	Seatpans (16*16)	dynamic time warping-based classifier	85.9%
Zemp et al. (2016b)	Adults	20	7	Seatpans (8*8)	random forest	82.7%

Table 2.9 System types and participant characteristics of previous studies related to development of sitting posture monitoring system

References	System type		Participant characteristics			
	Target user	Feedback?	Sampling method	Age	Numbers (male/female)	Anthropometric dimensions
Benocci et al. (2011)	Multi-user (even for unidentified users)	No	Stratified sampling (weight)	No info	7 (No info)	No info
Tan et al. (2001)	Single-user, multi-user (for both identified and unidentified user)	No	Random sampling	1. Single-user system: No info 2. Multi-user system: 18-60	1. single-user system: 1 (0/1) 2. multi-user system: 30 (15/15)	1. Single-user system: No info 2. Multi-user system: - Height (152-191 cm) - Weight (45.5-118.2 kg)
Xu et al. (2012)	Multi-user (even for unidentified users)	Yes (Visual)	Random sampling	20-31	7 (No info)	No info
Zheng and Morrell (2010)	Multi-user (only for identified user)	Yes (Vibrotactile)	No info	24±1.0	6 (4/2)	- Height (173±13.4 cm) - Weight (67.1±15.1 kg)

Table 2.9 (Continued)

References	System type		Participant characteristics			
	Target user	Feedback?	Sampling method	Age	Numbers (male/female)	Anthropometric dimensions
Chenu et al. (2009)	No info	Yes (Tongue Display Unit)	Random sampling	25.8±4.2	12 (No info)	No info
Ma et al. (2016)	Multi-user (only for identified user)	No	No info	No info	20 (12/8)	No info
Yu et al. (2013)	Single-user	Yes (Visual, Vibrotactile)	Random sampling for target population (office worker)	29.75±3.77	4 (2/2)	No info
Zemp et al. (2016b)	Multi-user (even for unidentified users)	No	Random sampling	24-64	41 (16/25)	- Height (177; 160-200 cm) - Weight (77; 53-126 kg)
Mota and Picard (2003)	Multi-user (even for unidentified users)	No	Random sampling	8-11	10 (5/5)	No info

Table 2.9 (Continued)

References	System type		Participant characteristics			
	Target user	Feedback?	Sampling method	Age	Numbers (male/female)	Anthropometric dimensions
Zheng and Morrell (2013)	No info	Yes (Visual, Vibrotactile)	No info	No info	No info	No info
Liang et al. (2014)	No info	Yes (results of control)	No info	No info	No info	No info
Shirehjini et al. (2014)	Multi-user (only for identified user)	No	No info	No info	50 (33/17)	- Height (150-198 cm) - Weight (50-100 kg)
Meyer et al. (2010)	Multi-user (even for unidentified users)	No	Random sampling	No info	9 (6/3)	No info
Xu et al. (2013)	No info	No	Random sampling	No info	25 (15/10)	No info

Table 2.9 (Continued)

References	System type		Participant characteristics			
	Target user	**Feedback?**	**Sampling method**	**Age**	**Numbers (male/female)**	**Anthropometric dimensions**
Xu et al. (2011)	Multi-user (only for identified user)	No	Random sampling	No info	10 (6/4)	No info
Martins et al. (2014)	Multi-user (even for unidentified users)	Yes	Random sampling	20.9	30 (15/15)	- Height (172.0 cm) - Weight (67.8 kg)
Zemp et al. (2016a)	Multi-user (even for unidentified users)	No	Random sampling for target population (office worker)	45 (25-57)	20 (13/7)	- Height (175; 160-189 cm) - Weight (71; 50-105 kg)
Ribeiro et al. (2015)	Multi-user (only for identified user)	Yes (Visual)	Random sampling	26.4±9.5	50 (25/25)	- Height (170.5±9.8 cm) - Weight (66.8±12.8 Kg)

Table 2.9 (Continued)

References	System type		Participant characteristics			
	Target user	Feedback?	Sampling method	Age	Numbers (male/female)	Anthropometric dimensions
Mutlu et al. (2007)	Multi-user (only for identified user)	No	Random sampling	1. Research using commercially-available system: No info 2. Research using deployed system: 19-34	1. Research using commercially-available system: 52 (26/26) 2. research using deployed system: 20 (10/10)	No info
Kazuhiro et al. (2008)	Multi-user (only for identified user)	No	Random sampling	21-24	10 (10/0)	Weight (57-90 Kg)
Bao et al. (2013)	Multi-user (only for identified user)	No	Random sampling for target population (disabilities or elderly)	No info	10 (No info)	No info
Cheng et al. (2013)	Single-user, multi-user (only for identified user)	No	Random sampling	23-34	5 (4/1)	No info

Table 2.9 (Continued)

References	System type		Participant characteristics			
	Target user	Feedback?	Sampling method	Age	Numbers (male/female)	Anthropometric dimensions
Pereira et al. (2015)	Multi-user (only for identified user)	No	Random sampling	26.6±9.3	72 (37/35)	- Height (170.8±9.4 cm) - Weight (67.7±12.7 Kg)
Zhu et al. (2003)	Multi-user (only for identified user)	No	Random sampling	No info	50 (25/25)	No info
Tessendorf et al. (2009)	Multi-user (only for identified user)	No	Random sampling	25-58	8 (5/3)	No info

Table 2.10 Experimental characteristics of previous studies related to development of sitting posture monitoring system

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Benocci et al. (2011)	7 (including not sitting)	Not seated, Upright, Leaning right, Leaning left, Right leg extended, Left leg extended, Both legs extended	Yes (Qualitative definition)	Self-managed	- Chair: No info (only figure) - Adjustment: No info - Posture control: No info
Tan et al. (2001)	1. Single-user system: 14 2. Multi-user system: 10	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Left leg crossed (with left foot on right knee), Right leg crossed (with knees touching), Right leg crossed (with right foot on left knee), Left foot on seatpan under right thigh, Right foot on seatpan under left thigh, Leaning left & Right leg crossed, Leaning right & Left leg crossed, Slouching	No	Copy	- Chair: Herman Miller (with figure) - Adjustment: No info - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Xu et al. (2012)	9	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Leaning forward & Leaning left, Leaning forward & Leaning right, Leaning backward & Leaning right, Leaning backward & Leaning right	No	No info	- Chair: No info (only figure) - Adjustment: No info (the chair in the figure seems to not adjustable) - Posture control: No info
Zheng and Morrell (2010)	10	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with left foot on right knee), Right leg crossed (with right foot on left knee), Leaning left & Right leg crossed, Leaning right & Left leg crossed, Slouching	Yes (Quantitative definition with figure)	Copy	- Chair: size B, fully adjustable Herman Miller Aeron chair with lumbar support (with figure) - Adjustment: Yes (Participants instructed to adjust the seat height and armrest height, then sit in the chair in front of a computer desk) - Posture control: Yes (their feet are flat on the floor and their thighs are parallel to the ground, elbows 90° on the armrest.)

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Chenu et al. (2009)	9	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Leaning forward & Leaning left, Leaning forward & Leaning right, Leaning backward & Leaning right, Leaning backward & Leaning right	No (only figure)	Copy	- Chair: No info (no figure) - Adjustment: No info - Posture control: No info
Ma et al. (2016)	6 (including not sitting)	Not seated, Upright, Leaning forward, Leaning backward, Leaning left, Leaning right	Yes (Qualitative definition)	Copy	- Chair: No info (office chair; only figure) - Adjustment: No info - Posture control: No info
Yu et al. (2013)	2 (Safe or not; they did not classify the postures specifically)	Safe posture, Unsafe posture	Yes (Qualitative definition)	Open	- Chair: No info (used participants' chair) - Adjustment: Yes (Desk and chair were adjusted based on the Guidelines for Video Display Terminal (VDT) Operators (Korean Department of Labor, 2004).) - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Zemp et al. (2016b)	7	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching)	No (Only figure)	Copy	- Chair: Three conventional office chairs (ID® chair, Vitra AG) - Adjustment: No info - Posture control: No info
Mota and Picard (2003)	9	Upright, Leaning forward, Leaning backward, Leaning forward & Leaning left, Leaning forward & Leaning right, Leaning backward & Leaning right, Leaning backward & Leaning right, Slouching, Sitting on the front edge	No	Self-managed	- Chair: SteelCase Leap chair - Adjustment: Yes (Seat pan and back rest altitude and openness were adjusted to each participant) - Posture control: No info
Zheng and Morrell (2013)	4	Upright, Leaning forward, Leaning backward, Slouching	Yes (Qualitative definition with figure)		- Chair: size B, fully adjustable Herman Miller Aeron chair with lumbar support - Adjustment: No info - Posture control: No info
Liang et al. (2014)	4	Upright, Leaning forward, Leaning left, Leaning right	No	No info	- Chair: No info (no figure) - Adjustment: No info - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	Postures & Definition	Define the posture?	Task Type	Settings
Shirehjini et al. (2014)	8	Upright, Leaning backward, Leaning left, Leaning right, Left leg crossed (with left foot on right knee), Right leg crossed (with right foot on left knee), Slouching, Sitting on the front edge	No (Only figure)	Copy	- Chair: No info (No figure) - Adjustment: No info - Posture control: No info
Meyer et al. (2010)	16	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Upright & Left leg crossed (with knees touching), Upright & Left leg crossed (with left foot on right knee), Upright & Right leg crossed (with knees touching), Upright & Right leg crossed (with right foot on left knee), Leaning backward & Left leg crossed (with knees touching), Leaning backward & Left leg crossed (with left foot on right knee), Leaning backward & Right leg crossed (with knees touching), Leaning backward & Right leg crossed (with right foot on left knee), Slouching, Slumping, Sitting on the front edge	No (Only figure)	Copy	- Chair: No info (no figure) - Adjustment: No info - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Xu et al. (2013)	7	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching)	No (Only figure)	Copy	- Chair: No info (No figure) - Adjustment: No info - Posture control: No info
Xu et al. (2011)	7	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching)	No (Only figure)	Copy	- Chair: No info (No figure) - Adjustment: No info - Posture control: No info
Martins et al. (2014)	5	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right	No (Only figure)	Copy	- Chair: No info (only figure) - Adjustment: Yes (The seat height was adjusted) - Posture control: Yes (Participants were instructed to empty their pocket and to keep their hands on their thighs while the knee angle was at 90°)

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Zemp et al. (2016a)	7	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching)	No (Only figure)	Copy	- Chair: No info (no figure; office chair; each participants' chair) - Adjustment: No info - Posture control: No info
Ribeiro et al. (2015)	12	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with left foot on right knee), Right leg crossed (with right foot on left knee), Left leg crossed (with knees touching), Right leg crossed (with knees touching), Leaning left & Right leg crossed (with right foot on left knee), Leaning right & Left leg crossed (with left foot on right knee), Slouching	No (Only figure)	Copy	- Chair: No info (only figure) - Adjustment: No info - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Mutlu et al. (2007)	10	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching), Leaning left & Right leg crossed, Leaning right & Left leg crossed, Slouching	No (Only figure)	Copy	- Chair: Herman Miller Aeron Chair (with figure) - Adjustment: No info - Posture control: No info
Kazuhiro et al. (2008)	9	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching), Leaning left & Left leg crossed, Leaning right & Right leg crossed, Slouching	No	Copy	- Chair: Only dimension of chair was described (back rest height (from the floor): 82cm, seat depth: 41cm, seat width: 42cm, seat height: 47cm) - Adjustment: None - Posture control: Yes (Each subject was first asked to sit down back (lean deeply))

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	Postures & Definition	Define the posture?	Task Type	Settings
Bao et al. (2013)	8 (including not sitting & 2 activities)	Not seated, Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Swinging, Shaking	No	Copy	- Chair: No info (wheelchair; only figure) - Adjustment: No info - Posture control: Yes (Participants were asked to natural backward, lightly against the backrest, eyes flat as the front left and right thighs roughly parallel, knees bent roughly 90 degrees, the foot gently flat on the ground.)
Cheng et al. (2013)	7	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching) or Right leg crossed (with knees touching), Left hand raised or Right hand raised	No	Copy	- Chair: No info (only figure; may be chair is not adjustable) - Adjustment: Yes (The subject is seated on the chair in front of a desk with a computer (may be all participants in same condition)) - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Pereira et al. (2015)	12	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with left foot on right knee), Right leg crossed (with right foot on left knee), Left leg crossed (with knees touching), Right leg crossed (with knees touching), Leaning left & Right leg crossed (with right foot on left knee), Leaning right & Left leg crossed (with left foot on right knee), Slouching	No (Only figure)	Copy	- Chair: No info (only figure) - Adjustment: Yes (seat height was adjusted) - Posture control: Yes (the knee angle (angle between the thigh and the leg) was at 90º and to keep their hands on their thighs.)
Zhu et al. (2003)	10	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Left leg crossed (with knees touching), Right leg crossed (with knees touching), Leaning left & Right leg crossed (with knees touching), Leaning right & Left leg crossed (with knees touching), Slouching	No	Copy	- Chair: No info (only figure) - Adjustment: No info - Posture control: No info

Table 2.10 (Continued)

References	Experimental characteristics				
	Number of postures	**Postures & Definition**	**Define the posture?**	**Task Type**	**Settings**
Tessendorf et al. (2009)	16	Upright, Leaning forward, Leaning backward, Leaning left, Leaning right, Upright & Left leg crossed (with knees touching), Upright & Left leg crossed (with left foot on right knee), Upright & Right leg crossed (with knees touching), Upright & Right leg crossed (with right foot on left knee), Leaning backward & Left leg crossed (with knees touching), Leaning backward & Left leg crossed (with left foot on right knee), Leaning backward & Right leg crossed (with knees touching), Leaning backward & Right leg crossed (with right foot on left knee), Slouching, Slumping, Sitting on the front edge	No	Copy	- Chair: No info (a wooden swivel chair with a flat surface; no figure) - Adjustment: Yes (The height of the chair was adapted to the length of the legs of the subjects.) - Posture control: Yes (Their heels were just touching the floor when sitting upright.)

Table 2.11 Measurement characteristics of previous studies related to development of sitting posture monitoring system

References	Measurement characteristics			
	Signal Type	**Settings**	**Additional Input**	**Acquisition device**
Benocci et al. (2011)	Pressure (5 points)	Seatpans (4), Backrest (1)	- Yaw angle of user rotation (magnetometer) - Magnitude of user movement (accelerometer)	Customized device (using Force Sensitive Resistor (FSR) (No info of manufacturer))
Tan et al. (2001)	Pressure (4032 points)	Seatpans (42*48), Backrest (42*48)	No Additional Input	Commercial device (Body Pressure Measurement System (BPMS) manufactured by Tekscan)
Xu et al. (2012)	Binary pressure (64 points)	Seatpans (6*8), Backrest (2*8)	No Additional Input	Customized device (using binary pressure sensor (threshold=3N) (No info of manufacturer))
Zheng and Morrell (2010)	Pressure (7 points)	Seatpans (5), Backrest (2)	No Additional Input	Customized device (using Force Sensitive Resistors manufactured by Interlink Electronics (Model: FSR 406))
Chenu et al. (2009)	Pressure (1024 points)	Seatpans (32*32)	No Additional Input	Commercial device (FSA Seat 32/63 pressure mapping system manufactured by Vista Medical)
Ma et al. (2016)	Pressure (3 points)	Seapans (2), Backrest (1)	No Additional Input	Customized device (using Force Sensitive Resistor (FSR) manufactured by Interlink Electronics (No info of model)

Table 2.11 (Continued)

References	Measurement characteristics			
	Signal Type	Settings	Additional Input	Acquisition device
Yu et al. (2013)	Binary pressure (9 points)	Seatpans (4), Backrest (3), Footrest (2)	No Additional Input	Customized device (using micro switch manufactured by Hanyoung Nux, South Korea (Model: HY-P701A [Z4G1P05B]))
Zemp et al. (2016b)	Pressure (16 points)	Seatpans (10), Backrest (4), Armrest(6)	- Backrest angle (using Motion-Module (accelerometer, gyroscope, and magnetometer; MPU-9250 Nine-Axis, MEMS Motion-Tracking Devices, InvenSense, California, USA))	Customized device (using Force Sensitive Resistors (FSR) manufactured by Interlink Electronics (Model: FSR 406))
Mota and Picard (2003)	Pressure (4032 points)	Seatpans (42*48), Backrest (42*48)	No Additional Input	Commercial device (Body Pressure Measurement System (BPMS) manufactured by Tekscan)
Zheng and Morrell (2013)	Pressure (6 points)	Seatpans (4), Backrest (2)	User location (head or back) (using infrared distance sensor (SHARP GP2D120, 4-30 cm range))	Customized device (using Force Sensitive Resistors (FSR) manufactured by Interlink Electronics (Model: FSR 406))
Liang et al. (2014)	Pressure (No info)	Seatpans (cushion) (No info)	No Additional Input	Customized device (No info)

Table 2.11 (Continued)

References	Measurement characteristics			
	Signal Type	**Settings**	**Additional Input**	**Acquisition device**
Shirehjini et al. (2014)	Binary pressure (8 points)	Seatpans (4), Backrest (4)	No Additional Input	Customized device (binary pressure sensor manufactured by General Electric (No info of model)
Meyer et al. (2010)	1. Customized device: Pressure (241 points; 97 out of 241 sensor elements have been preselected) 2. Commercial device: Seatpans (1025 points)	1. Customized device: Seatpans (240; a total of 96 out of 240 sensor elements have been preselected), Backrest (1) 2. Commercial device: Seatpans (32*32), Backrest (1)	No Additional Input	1. Customized device (using textile pressure sensor fully developed by researcher) 2. Commercial device (ConfortMat manufactured by Tekscan)
Xu et al. (2013)	Pressure (256 points)	Seatpans (16*16)	No Additional Input	Customized device (using textile pressure sensor fully developed by researcher)
Xu et al. (2011)	Pressure (256 points)	Seatpans (16*16)	No Additional Input	Customized device (using textile pressure sensor fully developed by researcher)
Martins et al. (2014)	Pressure (8 points)	Seatpans (8)	No Additional Input	Customized device (using piezoelectric gauge pressure sensor manufactured by Honeywell (Model: 24PC Series))

Table 2.11 (Continued)

References	Measurement characteristics			
	Signal Type	Settings	Additional Input	Acquisition device
Zemp et al. (2016a)	Pressure (64 points)	Seatpans (8*8)	No Additional Input	Commercial device (Pressure Sensor Tex manufactured by SensingTex (Model: PST04); using this device, researcher developed own system)
Ribeiro et al. (2015)	Pressure (8 points)	Seatpans (2*2), Backrest (2*2)	No Additional Input	Customized device (using piezoelectric gauge pressure sensor manufactured by Honeywell (Model: 24PC Series))
Mutlu et al. (2007)	1. Research using commercially-available system: Pressure (4032 points) 2. Research using deployed system: Pressure (19 points)	1. Research using commercially-available system: seatpans (42*48), backrest (42*48) 2. Research using deployed system: seatpans (11), backrest (8)	No Additional Input	- Commercial device (CONFORMat manufactured by Tekscan) - Customized device (using Force Sensitive Resistors (FSR) manufactured by Interlink Electronics (No info of model))
Kazuhiro et al. (2008)	Pressure (64 points)	Seatpans (8*8)	No Additional Input	Customized device (using Force Sensitive Resistors (FSR) manufactured by Tekscan (Flexiforce))

Table 2.11 (Continued)

References	Measurement characteristics			
	Signal Type	**Settings**	**Additional Input**	**Acquisition device**
Bao et al. (2013)	Pressure (5 points)	Seatpans (5)	No Additional Input	Customized device (using Force Sensitive Resistors (FSR) (No info of manufacturer))
Cheng et al. (2013)	Pressure (4 points)	bottom of the chair legs (4)	No Additional Input	Customized device (using pressure sensor based on polyethylene foam fully developed by researcher)
Pereira et al. (2015)	Pressure (8 points)	Seatpans (2*2), Backrest (2*2)	No Additional Input	Customized device (using piezoelectric gauge pressure sensor manufactured by Honeywell (Model: 26PC Series))
Zhu et al. (2003)	Pressure (4032 points)	Seatpans (42*48), Backrest (42*48)	No Additional Input	Commercial device (Body Pressure Measurement System (BPMS) manufactured by Tekscan)
Tessendorf et al. (2009)	Pressure (1024 points)	Seatpans (32*32)	No Additional Input	Commercial device (CONFORMat manufactured by Tekscan)

Table 2.12 Analysis method characteristics of previous studies related to development of sitting posture monitoring system

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Benocci et al. (2011)	- Normalization - Noise removal	Yes	kNN classifier	Leave-One-Out (LOO) cross-validation	92.7%
Tan et al. (2001)	- Noise removal - Normalization	1. Single-user system: No info 2. Multi-user system: Yes	PCA-Based Classification Algorithms	1.Single-user system: No info 2.Multi-user system: - For familiar user validation: Hold-out (test dataset was acquired from existing participants) - For unfamiliar user validation: Hold-out (test dataset was acquired from new participants)	1. Single-user system: over 95% 2. Multi-user system - For Familiar user: 96% - For unfamiliar user: 79%

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Xu et al. (2012)	No info	No info	Hybrid cascade sitting posture classifier (combines several naïve Bayes classifiers into a cascade structure)	Leave-One-Out (LOO) cross-validation	82.3%
Zheng and Morrell (2010)	No	No	Rule-based	Hold-out (test dataset was acquired from existing participants)	86.4% (All postures), 93.8% (4 postures)
Chenu et al. (2009)	No	Yes	Rule-based	No info	No info
Ma et al. (2016)	No	No	DT, SVM, MLP	10-fold cross-validation	99.5%(DT), 81.5%(SVM), 99.7%(MLP)
Yu et al. (2013)	No	No	Rule-based	Exploratory test	No info

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Zemp et al. (2016b)	No	Yes	SVM, MLR, Boosting, NN, RF, Combination of Boosting, NN and RF	Leave-One-Out (LOO) cross-validation	82.7% (SVMs), 87.8% (MNR), 90.4% (Boosting), NN (90.4%), 90.9% (RF), 90.8% (combination)
Mota and Picard (2003)	Noise removal	Yes	- NN	Hold-out (test dataset was acquired from new participants)	87.64%
Zheng and Morrell (2013)	No info	No info	Rule-based	No info	93.8%
Liang et al. (2014)	No info	No info	Adaboost	No info	No info
Shirehjini et al. (2014)	No	No	Rule-based	Hold-out (test dataset was acquired from existing participants)	Cohen-Kappa index = 0.48 (All postures), 0.62 (Except posture 7 and 8)

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	Feature extraction?	Algorithms	Validation method	Overall Accuracy
Meyer et al. (2010)	Interpolation	Yes	Naive Bayes classifier	Leave-One-Out (LOO) cross-validation	- Customized: 55% (only seat sensor), 81% (with back sensor) - Customized (Hysteresis compensated): 59% (only seat sensor), 82% (with back sensor) - ConfortMat: 56% (only seat sensor), 84% (with back sensor)
Xu et al. (2013)	Re-sampling	Yes	Dynamic time warping-based classification	No info	85.9%
Xu et al. (2011)	Noise removal	Yes	Dynamic time warping-based classification	Hold-out (test dataset was acquired from existing participants)	92% (based on self-training data), 79% (with general data)
Martins et al. (2014)	Normalization	No	NN	Leave-One-Out (LOO) cross-validation	98.1%
Zemp et al. (2016a)	Data reduction (averaging)	No	RF	Leave-One-Out (LOO) cross-validation	82.7%

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Ribeiro et al. (2015)	Data reduction (averaging)	No	- Posture classification: NN - Gender classification: CART	But this Neural Network Optimization only works in situations where the user identifies itself	- Posture classification: 89.0% (the highest accuracy) * - Gender identification: 97.9% (the highest accuracy) - Overall: 87.1% (the highest accuracy)
Mutlu et al. (2007)	No	- Research using commercially-available system: Yes - Research using deployed system: No	- Research using commercially-available system: a classifier based on Logistic Regression (LR) - Research using deployed system: a Simple Logistic classifier	10-fold cross-validation	- Research using commercially-available system: 87% - Research using deployed system: 78%

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Kazuhiro et al. (2008)	- Noise removal - Data reduction (cutoff unstable data) - Normalization	No	SVM	10-fold cross-validation	93.9% (Normalized by position & weight) - unknown 98.9% (Normalized by position & weight) - known
Bao et al. (2013)	No	No	Density-based clustering methods	No info	94.2% (for familiar; 94.2% in static posture classification)
Cheng et al. (2013)	No	Yes	LDA classifier	10-fold cross-validation	82.6% (with subject dependent training), 62.9% (all subjects is merged into one)
Pereira et al. (2015)	Data reduction (averaging)	No	NN	Hold-out (test dataset was acquired from existing participants)	80.9%

Table 2.12 (Continued)

References	Analysis method characteristics				
	Pre-processing?	**Feature extraction?**	**Algorithms**	**Validation method**	**Overall Accuracy**
Zhu et al. (2003)	- Data reduction (crop particular image and resizing)	No info	Sliced Inverse Regression (SIR) algorithm	Hold-out (test dataset was acquired from existing participants)	Over 86% (in graph, doesn't report the accuracy numerically)
Tessendorf et al. (2009)	Normalization	No	Adaptive Resonance Theory (ART) algorithms (unsupervised database approach)	Resubstitution	91% (Classification Ratio), 86% (Ground Truth Ratio)

Chapter 3

Anthropometric mismatch between furniture height and children in Korean primary schools

3.1 Introduction

Most children spend a considerable amount of time at school (Kumar, 1994; Troussier et al., 1999). In fact, they spend more than one quarter of a day in schools, of which 80% of the time involves sedentary activities (e.g., lessons). However, adopting awkward postures during prolonged sitting hours can cause musculoskeletal diseases (Pynt et al., 2001; Takemitsu et al., 1988). In particular, the lumbar disorder that occurs during childhood can inhibit the physical development of children in the growing phase (Tanner et al., 1976), and even if treated, it is expected to recur in adulthood (Troup et al., 1987). Furthermore, the poor postural habits formed in childhood are not easily corrected in adulthood (Yeats, 1997). Therefore, it is important to encourage children to maintain good posture while sitting.

The adoption of inappropriate sitting postures by children can be attributed to various factors such as preference, physical defects, lacking knowledge of good postures, defective sight, and fatigue (Elliott and Morrison, 1946; Hummel, 1943). One of the major factors is the use of anthropometrically mismatched furniture (Oyewole et al., 2010). In particular, the mismatched height of a desk or chair can force children to sit awkwardly. Agha (2010) found that children posed abnormally, such as by sliding forward on a seat or placing a leg between the seat surface and the buttock when the seat height was extremely high for them. It was observed that if the height of the desk was extremely low, the children bent their upper body forward. They also adopted inappropriate sitting postures such as excessive shoulder flexion or abduction when the desk height was very high. Additionally, Panagiotopoulou et al. (2004) confirmed that the mismatched heights of desks and chairs caused children to sit with poor posture. When the height of a seat was very high, children placed their buttocks forward on the front edge of the seat. Moreover, if the desk height was higher than the elbow rest height, children adopted awkward sitting postures such as elevating their arms and shoulders. Therefore, the heights of school desks and chairs should be carefully determined by considering the anthropometric characteristics of children.

The International Organization for Standardization (ISO) published the ISO 5970 standard in 1979. This is a guideline for the design of school furniture (ISO, 1979). Additionally, various countries such as the United Kingdom (BSI, 1980, 2006), Chile (INN, 2002), and Indonesia (NSAI, 1989a, b) have their own standards with regard to the anthropometric characteristics of children in each country. In Korea, the KSG-2010 standard (KSA, 2015) was published based on the ISO 5970 standard. Consequently, in Korea, the fabrication of school furniture must comply with this standard. KSG-2010 suggests seven levels for desk and chair height systems. However, in 2001, these height systems were revised based on the Korean anthropometric data obtained in 1997. Even though the height systems were developed to reflect the anthropometric characteristics of Korean children, 16 years have passed since their last revision. With regard to the secular trend of significantly increasing body size (Moon, 2011), it is uncertain whether the desks and chairs made in accordance to the standard are still suitable to the current generation of Korean children.

Recently, height adjustable desks and chairs have become widespread in Korean schools to accommodate more children. However, these desks and chairs are discretely adjustable within the seven level ranges. According to KSG-2010, the desk and seat heights have fixed values at each level. However, the values of other dimensions (e.g., below desk height, seat depth, seat width, and backrest height) are not fixed at each level. Therefore, they range between a standard minimum value and maximum value. Thus, under the assumption that the children in every school are not quite different to each other, the degree of mismatch for the desk and seat heights in Korean primary schools is consistent, in contrast with the degree of mismatch for other dimensions.

Numerous studies have been conducted to survey the anthropometric characteristics of students and evaluate the anthropometric suitability of school furniture in several countries including Greece (Panagiotopoulou et al., 2004), Gaza strip (Agha, 2010), Chile (Castellucci et al., 2010), Saudi Arabia (Ramadan, 2011), United Arab Emirates (UAE) (Bendak et al., 2013), and Indonesia (Yanto et al., 2017). Remarkably, all of these studies reported that the height of the investigated school furniture did not match well. Panagiotopoulou et al. (2004) collected anthropometric data from 180 elementary school students (90 males and 90 females) aged from 7 to 12 years in the Thessaloniki region of Greece and analyzed the degree of mismatch to school furniture dimensions. Two types of desks and chairs were used, and the mismatch between the school furniture dimensions and the anthropometric data was analyzed by the graders. The results revealed that the seat and desk heights matched by 55-60% and 68.3-80%, respectively, which implies that up to a 45% mismatch was confirmed for the seat height. Agha (2010) measured the anthropometric dimensions of 600 children aged from 6 to 11 years old. He revealed that the mismatch for the seat and desk heights was approximately 100%. The author proposed a new design for lower and upper graders and analyzed the mismatch in a similar manner. The results revealed that the suggested heights of the seats and desks were suitable for more than half of the students. Castellucci et al. (2010) reported the degree of mismatch based on the anthropometric data collected from 195 students (94 males, 101 females) aged between 12 and 14. The seat height matched at least 14%, and the seat to desk height had a mismatch of approximately 100%. Ramadan (2011) conducted a mismatch study for height adjustable desk and chair with four levels. The anthropometric dimensions were measured from 124 students between the ages of 6 and 13, who are the first to sixth graders in Saudi Arabia. Accordingly, the highest degree of mismatch for the seat height was 92.8%, while the lowest was 7.3%. In the case of desk height, the maximum mismatch was 100%, while the minimum mismatch was 9.7%. Bendak et al. (2013) collected anthropometric data from 200 sixth graders (100 males and 100 females) in Dubai and the Sharjah region of the UAE to assess the classroom furniture dimensions in terms of ergonomics. The seat height matched 32% of the students of one school. In case of the other school, the seat height was not matched by any student. The seat to desk height in the two schools was matched by 20% and 26% of the students. In the case of the seat to desk clearance, 25% of the students touched the desk, which could limit the movement of their feet. Yanto et al. (2017) conducted a mismatch study of small and large types of Indonesian elementary school furniture for a population of 1,146 students (male: 584, female: 562) aged between 6 and 12. The seat height mismatched 63.4% of the students at its lowest level and 99% at its highest level. The desk height mismatched 32.3% of the students at its lowest level and 99% at its highest level. To enhance the degree of matching, they proposed a new size system based on existing studies and demonstrated that it could achieve an increase in the degree of matching. However, such studies with regard to Korean primary school furniture are lacking. Several studies have reviewed ergonomically the present size systems of Korean school furniture. However, these studies are outdated and also did not carry out a quantitative analysis of the degree of matching (Chung and Park, 1986; Kim et al., 2006; Min, 2007).

This study conducted a mismatch analysis for the height systems of the desks and chairs used in Korean primary schools, based on the recent anthropometric data of Korean children. Moreover, this study proposed new height systems of desk and chair by adopting an algorithmic approach to increase the degree of matching.

3.2 Methods

3.2.1 Present height systems of desks and chairs in Korean primary schools

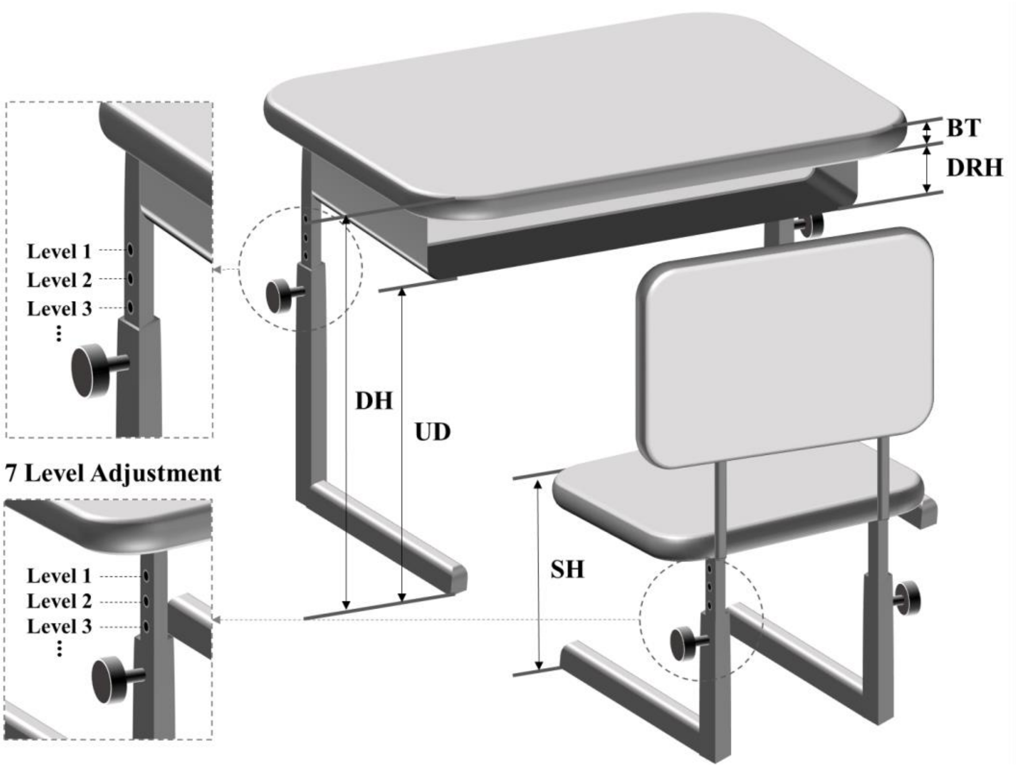


Figure 3.1 Illustration of present school furniture and dimensions considered in this study. Desk height (DH): vertical distance from the floor to the tip of the front edge of the board of the desk; underneath desk height (UDH): vertical distance from floor to lowest point below the drawer; board thickness (BT): thickness of the front edge of the board of the desk; drawer height (DRH): vertical distance from the lowest point below the drawer to the lowest point below the front edge; seat height (SH): vertical distance from floor to middle point of the front edge of the sitting surface

As mentioned above, the desk height at Korean primary schools can be adjusted up to seven levels (Figure 3.1). According to KSG-2010, each level of the desk height (DH) is 400, 460, 520, 580, 640, 700, and 760 mm. All desks have a drawer attached underneath their board. Subsequently, the underneath desk height (UDH) at each level depends on the board thickness (BT) and drawer height (DRH). Note that the height difference between the DH and UDH must be designed as less than 110 mm, whereas, the DRH should be more than 70 mm according to KSG-2010. Therefore, all desks do not have to be designed with same UDH at the same DH level. In this study, it was assumed that the BT was 20 mm and DRH was 70 mm, which are average values for the desks used in Korean primary schools. The chairs used in Korean primary schools can be adjusted up to seven levels of seat height (SH), as can the desk, each being 220, 260, 300, 340, 380, 420, and 460 mm (Figure 3.1).

3.2.2 Anthropometric data

This study employed anthropometric data measured by the National Anthropometric Survey (6th Size Korea, KATS) in 2010. Among the data of the 139 anthropometric measures for Koreans aged from 7 to 69 years old, the data of the following five anthropometric measures for children aged from 7 to 12 (n = 4014) were selected: popliteal height, sitting (PH); knee height, sitting (KH); shoulder height, sitting (ShH); elbow height, sitting (EH); and stature (S) (Figure 3.2). The descriptive statistics of the five anthropometric measures of the children are presented in Table 3.1.

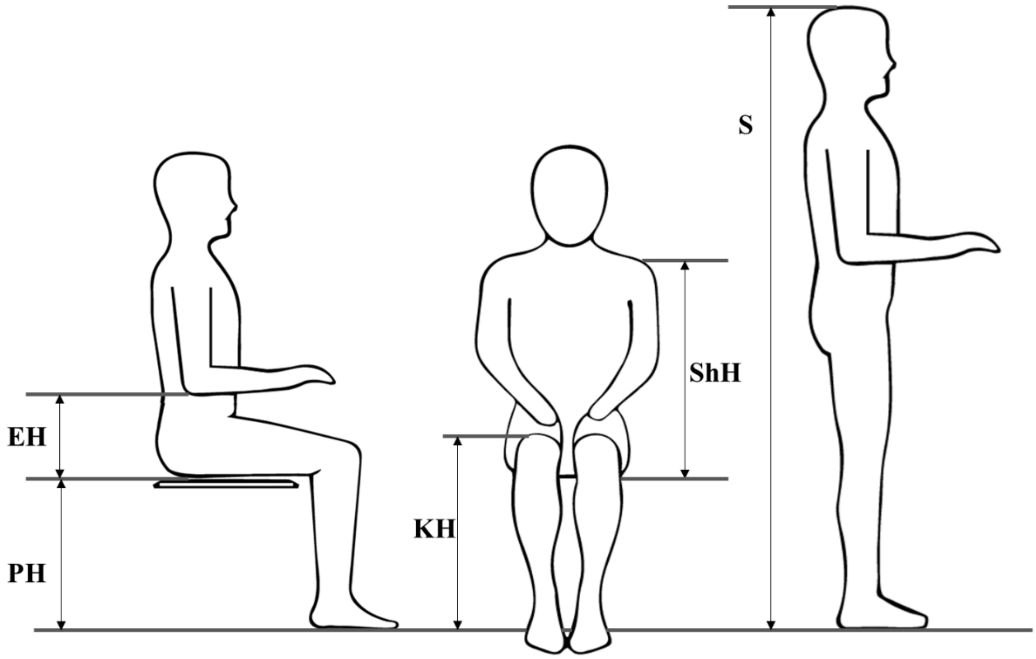


Figure 3.2 Anthropometric measures used in this study. Stature (S): vertical distance from floor to vertex in the anthropometric standing posture; elbow height, sitting (EH): vertical distance from the sitting surface to bottom olecranon in anthropometric sitting posture; shoulder height, sitting (ShH): vertical distance from sitting surface to acromion in anthropometric sitting posture; knee height (KH): vertical distance from floor to suprapatellar in anthropometric sitting posture; popliteal height, sitting (PH): vertical distance from floor to posterior juncture of calf and thigh in anthropometric sitting posture

Table 3.1 Anthropometric measures of Korean children

Age	Descriptive statistics	S (mm)	ShH (mm)	EH (mm)	KH (mm)	PH (mm)
7 (n=480)	5^{th}	1,131.05	366.05	141.00	332.00	267.00
	50^{th}	1,208.00	400.00	168.00	364.00	294.00
	95^{th}	1,294.95	436.95	196.00	399.00	324.00
	Mean	1,209.39	400.77	168.30	364.73	294.15
	SD	50.533	21.342	16.493	19.901	17.771
8 (n=505)	5^{th}	1,190.00	385.60	148.00	354.30	283.30
	50^{th}	1,274.00	421.00	175.00	389.00	311.00
	95^{th}	1,357.70	460.70	205.00	421.00	342.70
	Mean	1,271.85	421.98	175.68	387.96	311.36
	SD	53.853	22.835	17.593	20.402	17.959
9 (n=618)	5^{th}	1,236.00	402.00	152.95	374.00	300.95
	50^{th}	1,332.00	439.00	179.00	411.00	329.00
	95^{th}	1,425.05	482.00	214.00	448.05	360.05
	Mean	1,332.36	440.63	181.03	411.08	329.67
	SD	57.631	24.469	18.670	22.483	18.002
10 (n=703)	5^{th}	1,283.40	417.00	156.20	392.00	313.00
	50^{th}	1,379.00	455.00	185.00	429.00	342.00
	95^{th}	1,489.00	503.80	220.00	470.00	378.80
	Mean	1,383.32	456.67	186.40	430.18	343.45
	SD	60.913	26.331	19.536	23.535	19.419
11 (n=857)	5^{th}	1,334.80	432.00	162.00	409.00	325.00
	50^{th}	1,446.00	476.00	194.00	450.00	359.00
	95^{th}	1,555.00	523.00	230.00	493.10	397.10
	Mean	1,445.13	476.90	194.64	450.03	359.14
	SD	68.544	28.394	19.989	25.130	21.276
12 (n=851)	5^{th}	1,401.00	448.00	169.00	427.00	336.00
	50^{th}	1,518.00	503.00	203.00	471.00	375.00
	95^{th}	1,628.00	556.00	244.00	512.40	412.00
	Mean	1,516.53	502.95	204.61	471.01	375.02
	SD	70.202	32.009	22.776	25.614	22.242
Total (n=4014)	5^{th}	1,192.00	390.00	153.00	356.00	285.00
	50^{th}	1,382.00	456.00	186.00	428.00	341.00
	95^{th}	1,575.00	530.00	229.00	494.00	395.00
	Mean	1,382.09	457.28	187.68	427.00	341.44
	SD	118.466	42.757	22.980	42.052	33.237

3.2.3 Mismatch equations of desk and seat height

The mismatch equations of school furniture define the minimum and maximum limit of the furniture dimensions by using the anthropometric measures. In previous studies, several mismatch equations for the DH, UDH, and SH have been proposed.

Most studies that analyzed the mismatch of the DH regarded the following situation as a mismatch situation: when the children sit upright and rest their elbow on the desk, their shoulder joints are flexed significantly. However, the studies were different with regard to the selection of relevant anthropometric measures. Some studies defined only the EH as the related anthropometric measure (Castellucci et al., 2010; Dianat et al., 2013). On the other hand, other studies considered both EH and ShH (Afzan et al., 2012; Agha, 2010; Batistao et al., 2012; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Gouvali and Boudolos, 2006; Panagiotopoulou et al., 2004; Parcells et al., 1999; Ramadan, 2011). Chung and Wong (2007) and Cotton et al. (2002) defined only the upper limit of the DH. Cotton et al. (2002) and Parcells et al. (1999) considered the backward slope of a chair and revised the EH by considering a backward lean toward a back support.

Most of the studies that analyzed the mismatch of UDH defined the following situation as a mismatch situation: when children sit in the front of a desk, their legs are difficult to place underneath the desk due to insufficient desk clearance (DC). However, these studies revealed differences in the selection of relevant measures. Some studies have considered the KH (Agha, 2010; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Gouvali and Boudolos, 2006; Panagiotopoulou et al., 2004; Parcells et al., 1999), whereas one of the others considered the thigh thickness (Castellucci et al., 2010) to define the mismatch equation of the UDH. Gouvali and Boudolos (2006) uniquely defined the upper limit of the UDH by assuming a BT of 4 cm. This study selected the mismatch equations for the DH and UDH which consider the shoe sole thickness (ST) and define both the lower limit and upper limit in terms of both the EH and SH (Equations (1) and (2);

provided by Gouvali and Boudolos (2006)). According to the abovementioned desk structure (Equation (3)), the degree of mismatch for the DH can be calculated by incorporating the equations for the DH and UDH (Equation (4)). In this study, the ST and DC were assumed to be 20 mm (Gouvali and Boudolos, 2006), based on previous studies, whereas the BT and DRH were assumed to be 20 mm and 70 mm, respectively.

Most previous studies which investigated the mismatch of the SH considered the following situation as a mismatch situation: when both the feet of the seated child are horizontally rested either on the floor or on a foot rest, the knee joint angle is out of the appropriate range (5 to 30°). However, some studies considered the ST (Afzan et al., 2012; Agha, 2010; Castellucci et al., 2010; Dianat et al., 2013; Gouvali and Boudolos, 2006), while others did not (Batistao et al., 2012; Brewer et al., 2009; Chung and Wong, 2007; Cotton et al., 2002; Jayaratne and Fernando, 2009; Jayaratne, 2012; Panagiotopoulou et al., 2004; Parcells et al., 1999; Ramadan, 2011; van Niekerk et al., 2013). In this study, the degree of mismatch with regard to the SH was calculated by the equation considering the ST, as expressed by Equation (5) (Gouvali and Boudolos, 2006).

As you can see in the mismatch equation for the DH (Equation (4)), this equation includes the mismatch equation for the SH (Equation (5)). In other words, the mismatch equation for the DH means that the DH needs to be in a range of anthropometrically recommendable elbow rest height while sitting on a chair whose SH is anthropometrically recommendable. According to this fact, it could be possible to conduct mismatch analyses of DH and SH independently in spite of the fact that desk and chair needs to be treated as a system.

$$\mathrm{EH} + [(\mathrm{PH} + ST)\cos 30°] \leq DH \\ \leq (0.8517\mathrm{EH}) + (0.1483\mathrm{ShH}) + [(\mathrm{PH} + ST)\cos 5°]. \tag{1}$$

$$(\mathrm{KH} + ST) + DC \leq UDH \\ \leq (0.8517\mathrm{EH}) + (0.1483\mathrm{ShH}) + [(\mathrm{PH} + ST)\cos 5°] - (BT \\ + DRT). \tag{2}$$

$$DH = UDH + BT + DRT. \tag{3}$$

$$\max(\mathrm{EH} + [(\mathrm{PH} + ST)\cos 30°], (\mathrm{KH} + ST) + DC + BT + DRT) \leq DH \\ \leq (0.8517\mathrm{EH}) + (0.1483\mathrm{ShH}) + [(\mathrm{PH} + ST)\cos 5°]. \tag{4}$$

$$(\mathrm{PH} + ST)\cos 30° \leq SH \leq (\mathrm{PH} + ST)\cos 5°. \tag{5}$$

3.2.4 Data treatment

The minimum acceptable limit (minAL) and maximum acceptable limit (maxAL) of the DH and SH for the 4,014 children were calculated based on Equations (4) and (5). Consequently, it was verified whether the DH and SH per level matched each child. From the results, the following values were calculated from the levels of the DH and SH: frequencies of match, mismatch because of exceeding the maxAL, and mismatch because of missing the minAL. Moreover, the proportion of children who was possible to match with at least one of the levels was calculated by their ages. All the analyses were performed using Excel 2016 (Microsoft) and SPSS 24.0 (IBM).

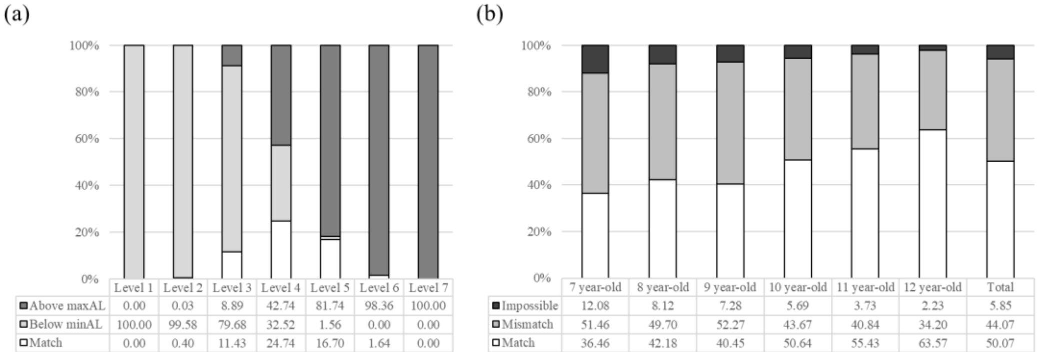
3.3 Results

3.3.1 Mismatch of desk height

Figure 3.3 (a) presents the percentage of the mismatched children, when each level of the DH is used. Because of missing the minAL, none of the children matched with Level 1. Level 2 matched with 0.4% of the children, whereas there existed a mismatch of 0.03% as a result of exceeding the maxAL, and a mismatch of 99.58% because of missing the minAL. In the case of Level 3, there was 11.43% match and 8.89% mismatch because of exceeding the maxAL and 79.68% mismatch because of missing the minAL. For Level 4, there was 24.74% match, and 42.74% and 32.52% mismatch as a result of exceeding the maxAL and missing the minAL, respectively. Level 5 matched with 16.70% of the children as it mismatched with 81.74% because of exceeding the maxAL and 1.56% because of missing the minAL. In the case of Level 6, 1.64% of the children were matched, while the remaining 98.36% were mismatched because of exceeding the maxAL. Finally, Level 7 DH did not match with any child as a result of exceeding the maxAL.

The degree of mismatch by age is shown in Figure 3.3 (b). It can be seen that 50.07% of children had at least one level to match among the seven levels, whereas 5.85% of the children were impossible to match because their calculated minAL was larger than the maxAL. In terms of age groups, 36.46% of the 7-year-old children had at least one matching level, whereas 12.08% of them were impossible to match. In the case of 8-year-old children, 42.18% matched with at least one level, whereas 8.12% were impossible. For 9-year-old children, 40.45% matched with at least one level, whereas 7.28% of them were impossible to match. With regard to 10-year-old children, 50.64% matched with at least one level, and 5.69% of them could not be matched. For 11-year-old children, 55.43% of them matched with at least one level, whereas 3.73% of them were impossible to match. Finally, regarding

12-year-old children, 63.57% matched with at least one level, whereas 2.23% were impossible.



	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Above maxAL	0.00	0.03	8.89	42.74	81.74	98.36	100.00
Below minAL	100.00	99.58	79.68	32.52	1.56	0.00	0.00
Match	0.00	0.40	11.43	24.74	16.70	1.64	0.00

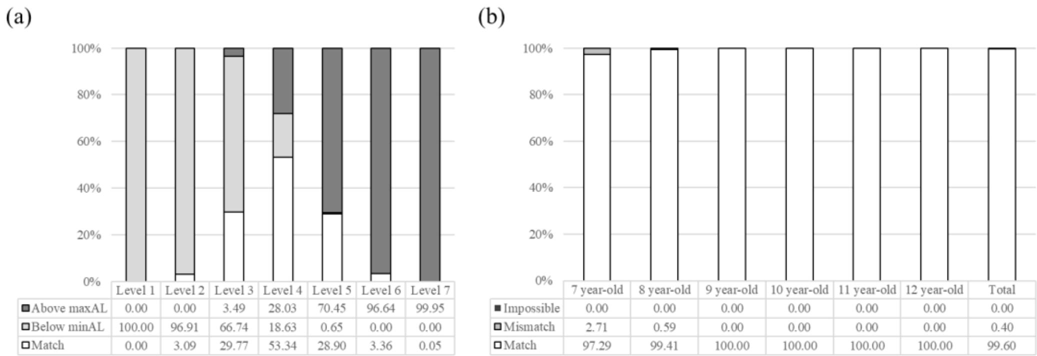
	7 year-old	8 year-old	9 year-old	10 year-old	11 year-old	12 year-old	Total
Impossible	12.08	8.12	7.28	5.69	3.73	2.23	5.85
Mismatch	51.46	49.70	52.27	43.67	40.84	34.20	44.07
Match	36.46	42.18	40.45	50.64	55.43	63.57	50.07

Figure 3.3 Degree of mismatch of the present height system for desks: (a) degree of mismatch at each level; (b) degree of mismatch by age

3.3.2 Mismatch of seat height

The degree of mismatch at each level of the SH is shown in Figure 3.4 (a). Level 1 did not match with any children because of missing the minAL. Level 2 matched with 3.09% of the children, while the remaining 96.91% mismatched because of missing the minAL. In the case of Level 3, 29.77% of the children matched, whereas 3.49 % mismatched because of exceeding the maxAL, and 66.47% mismatched because of missing the minAL. For Level 4, 53.34% matched, whereas 28.03% and 18.63% mismatched because of exceeding the maxAL and missing the minAL, respectively. Level 5 matched with 28.90% as it mismatched with 70.45% because of exceeding the maxAL and with 0.65% because of missing the minAL. In the case of Level 6, 3.36% of the children matched, whereas the rest of 96.64% mismatched because of exceeding the maxAL. Finally, Level 7 matched with 0.05% of the children and the rest of 99.95% mismatched because of exceeding the maxAL.

The degree of mismatch by age is displayed in Figure 3.4 (b). Among the all children, 99.60% matched with at least one out of the seven levels. In terms of the age groups, 2.71% and 0.59% of the 7- and 8-year-old children did not match with any level, respectively. Meanwhile, all of the 9 to 12 year-old children matched with at least one level.



	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
Above maxAL	0.00	0.00	3.49	28.03	70.45	96.64	99.95
Below minAL	100.00	96.91	66.74	18.63	0.65	0.00	0.00
Match	0.00	3.09	29.77	53.34	28.90	3.36	0.05

	7 year-old	8 year-old	9 year-old	10 year-old	11 year-old	12 year-old	Total
Impossible	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mismatch	2.71	0.59	0.00	0.00	0.00	0.00	0.40
Match	97.29	99.41	100.00	100.00	100.00	100.00	99.60

Figure 3.4 Degree of mismatch of the present height system for chairs: (a) degree of mismatch at each level; (b) Degree of mismatch by age

3.4 Analysis of anthropometric mismatch

3.4.1 Analysis of mismatch conditions

First, in the case of the DH, only 50.07% of the children were able to match with at least one of the seven levels. The actual degree of matching may be much lower, considering that the children may not use the appropriate desk height, even if appropriate levels are available for them. In particular, 5.85% of children were impossible to match regardless of desk height because the minAL exceeded the maxAL. This is because the height difference between the DH and UDH, i.e., the sum of BT and DRH, was extremely high for these children. The DRH of the desk in Korean primary schools is designed to have a minimum value of 70 mm and a maximum of 90 mm according to KSG-2010, under the assumption of BT being 20 mm. Figure 3.5 shows the ratio of the children who cannot be matched with an appropriate DH based on the DRH. When the DRH is high, the degree of mismatch increases rapidly. Younger children in particular are more likely to be affected by the DRH because, when considering the mismatch equation, a lower EH and ShH implies a smaller difference between the maxAL and minAL. Therefore, it is recommended to remove the desk drawers or minimize their height. Such a recommendation has also been made by previous studies (Castellucci et al., 2014; Oxford, 1969; Panagiotopoulou et al., 2004) and the national standards of some countries (BSI, 2006; INN, 2002). In addition, the height of each level should also be modified to increase the degree of matching as the results revealed that only levels 3, 4, and 5 could match with more than 10% of the children.

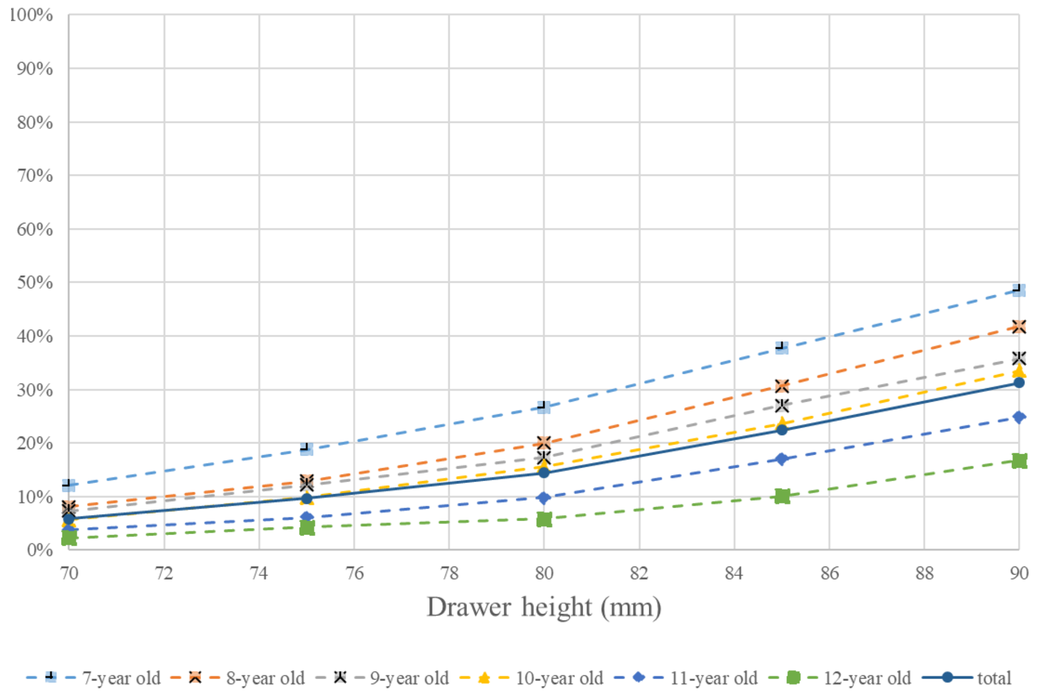


Figure 3.5 Proportion of children impossible to match with appropriate desk height based on drawer height

Secondly, with regard to SH, 99.60% of the children matched with at least one of the seven levels. However, the results revealed that only levels 3, 4, and 5 were effective, whereas the remaining levels matched with less than 5%. Considering the maximization of the number of matching children with a minimum number of levels as an ideal situation, a change in the height system of the chair is also recommended.

3.4.2 Possible design considerations

3.4.2.1 Removal of desk drawer

As mentioned above, a major cause of the mismatch of the DH was the presence of the desk drawers. The degree of mismatch at each level of the DH when the drawers are removed is shown in Figure 3.6 (a). In comparison with present desks, the degree of matching at some levels was significantly improved. For Level 1, 0.20% of the children matched, and the remaining 99.80% mismatched because of missing the minAL. At Level 2, 17.81% matched, whereas 0.22% mismatched because of exceeding the maxAL and 81.96% mismatched because of missing the minAL. At Level 3, 52.72% matched, whereas 10.81% and 36.47% mismatched because of exceeding the maxAL and missing the minAL, respectively. In the case of Level 4, 50.82% of the children matched, but 45.32% exceeded the maxAL and 3.86% fell short of the minAL. For Level 5, 17.12% matched, while 82.81% mismatched as a result of exceeding the maxAL and 0.07% mismatched because of missing the minAL. At Level 6, 1.54% matched, whereas the rest of 98.46% exceeded the maxAL. Finally, in the case of Level 7, none of the children matched because of exceeding the maxAL.

The degree of mismatch by age is presented in Figure 3.6 (b). The removal of the drawer resulted in a significant improvement in the degree of matching for all age groups, in comparison with the present desks. There were no children impossible to match, and 99.75% of the children in the age of 7 to 12 years had at least one seat height to match out of the seven levels. The degree of matching for 7 to 12-year-old children was 99.17 %, 100.00 %, 99.51 %, 99.86 %, 99.88 %, and 99.88 %, respectively.

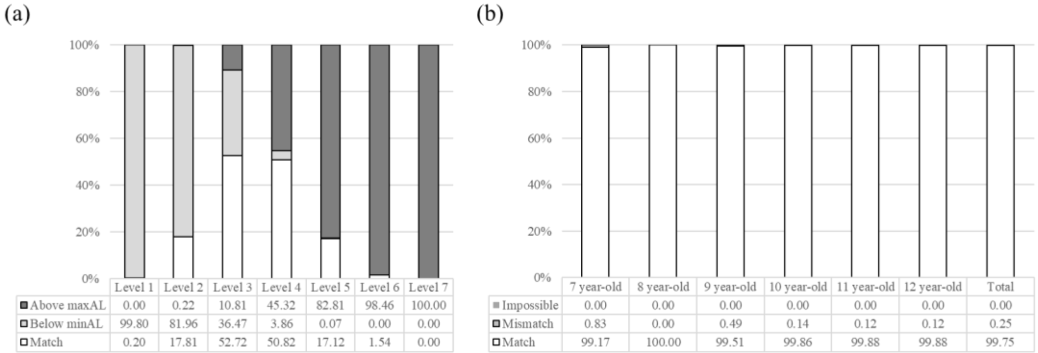


Figure 3.6 Degree of mismatch of the present height system for desks when drawer is removed: (a) degree of mismatch at each level; (b) degree of mismatch by age

3.4.2.2 Development of new desk and chair height systems

In this section, the new height systems for the desks and chairs are proposed. A new height system for the desk was developed to increase the degree of matching without removing the drawer and a new height system for the chair was developed to decrease the number of levels while preserving the degree of matching of present height system. The ellipse methodology is a typical method of developing a size system for school furniture (Carneiro et al., 2017; Castellucci et al., 2015b; Molenbroek et al., 2003). This method estimates the scatter plots between the reference anthropometric measure and the measures relevant to the furniture dimensions based on their 5th and 95th percentile values per age group. Most studies selected the stature or popliteal height as the reference measure. Subsequently, the seat height system was determined, and then other furniture dimensions were determined by using the estimated scatter plots based on the appropriate popliteal height range for each size derived from the determination of the seat height system. However, the size system developed by this method may not match the actual population as expected because the estimated scatter plot may be different to the actual scatter plot. Most importantly, this method is not feasible when a furniture dimension is associated with multiple anthropometric measures.

The problem of maximizing the number of children matching at least one of the several height levels resembles the maximum coverage problem, which is one of the classical problems in the fields of computer science, computational complexity theory, and operation research. Given a whole set and its subsets, the objective with regard to this problem is to determine the combination of subsets that can maximize the number of elements in the union of the selected subsets, when the number of subsets is given. Such a problem can be formulated with the following integer linear program:

$$\begin{aligned}
\text{maximize} \quad & \sum_{e_j \in E} y_j \\
\text{subject to} \quad & \sum x_i \leq k \\
& \sum_{e_j \in S_i} x_i \geq y_j \\
& y_j \in \{0, 1\} \\
& x_i \in \{0, 1\}
\end{aligned}$$

In the integer linear program shown above, e_j, S_i, y_j, x_i, k, and E represent the jth elements, i^{th} subset, coverage of e_j (if e_j is covered, y_j is 1), selection of S_i (if S_i is selected, x_i is 1), number of selected sets, and union of the sets, respectively. This problem is NP-hard, and it becomes more difficult to obtain the optimized solution as the target number of subsets and number of elements included in the whole set increase. In this study, the element corresponds to each child, whereas the subset corresponds to the set of children who can match with the candidate of the height of each level. Thus, the number of elements is defined as 4,014 (number of children), and the target number of subsets is seven (current number of levels). The simplest method to obtain the optimized solution is to compute and compare the degree of matching for all possible combination of levels. In the case of the DH, when a desk drawer is present (BT: 20 mm, DRH: 70 mm), the minimum value of minAL is 439 and the maximum value of maxAL is 759.88 among the 4,014 children. Assuming that the height at each level of the DH is an integer value on the millimeter-scale, the candidates at each level of DH are a total of 321 from 439 to 759, and the number of combinations is over 60 trillion (${}_{321}C_7$), resulting in an excessive calculation time. Therefore, an efficient approximation algorithm is required to solve the problem. The greedy algorithm which could be applied to the maximum coverage problem finds a solution in accordance with one rule: select the subset that contains the most number of uncovered elements. Despite the simplicity of this algorithm, so far, it is essentially the best-possible polynomial time approximation algorithm for the maximum coverage problem (Feige, 1998).

In this study, the algorithm was implemented in Python to obtain the approximately optimal set of levels. The results indicated that a total of 15 levels of the DH and 3 levels of the SH are required to match more than 90% of the children with one of the levels (Figure 3.7). In the case of the DH, the seven levels allow approximately 80% of children to be possible to match (Figure 3.7 (a)), and the heights at each level are 501, 528, 546, 557, 579, 606, and 643 mm, respectively. The degree of matching is shown in Figure 3.8. The degrees of matching at each level are 7.17%, 13.89%, 19.79%, 21.88%, 24.58%, 26.86%, and 15.72%, respectively, whereas the degrees of matching by age group are 57.92%, 75.45%, 82.69%, 83.36%, 85.53%, and 83.90%, respectively. Even though the degree of matching of the new desk for the all children may fall short of that of the present desk without a drawer, it is approximately 30% higher than that of the present desk with a drawer (Figure 3.10 (a)). In the case of SH, five levels allow a possible match for all children (Figure 3.7 (b)), and the heights at each level are 259, 298, 343, 394, and 413, respectively. The degree of mismatch is shown in Figure 3.9. The degrees of matching at each level are 2.67%, 28.48%, 53.64%, 16.09%, and 5.28%, respectively. Compared with the present chairs, all the children are matched with a smaller number of levels (Figure 3.10 (b)).

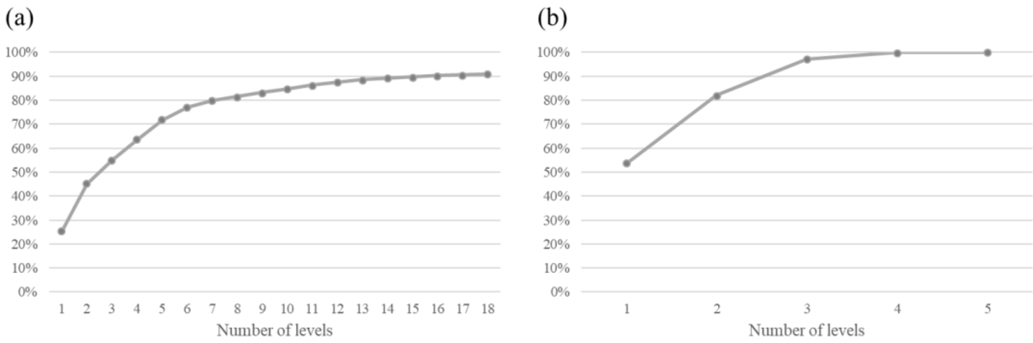


Figure 3.7 Possible degree of matching according to number of levels: (a) desk height; (b) seat height

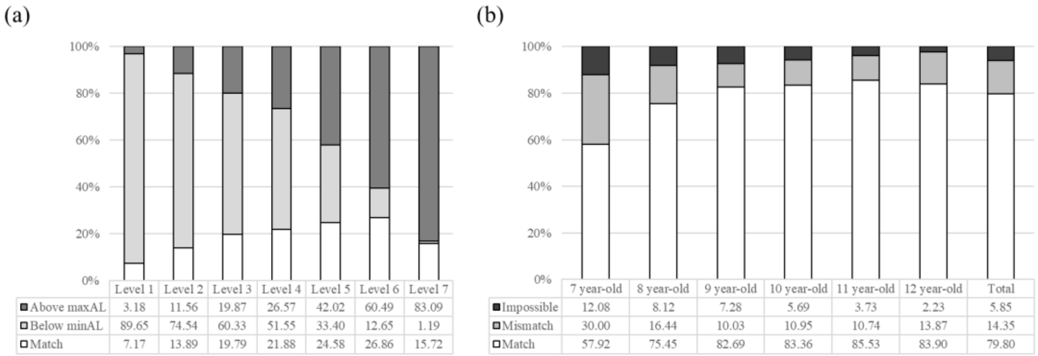


Figure 3.8 Degree of mismatch of new height system for desks: (a) degree of mismatch for each level; (b) degree of mismatch by age

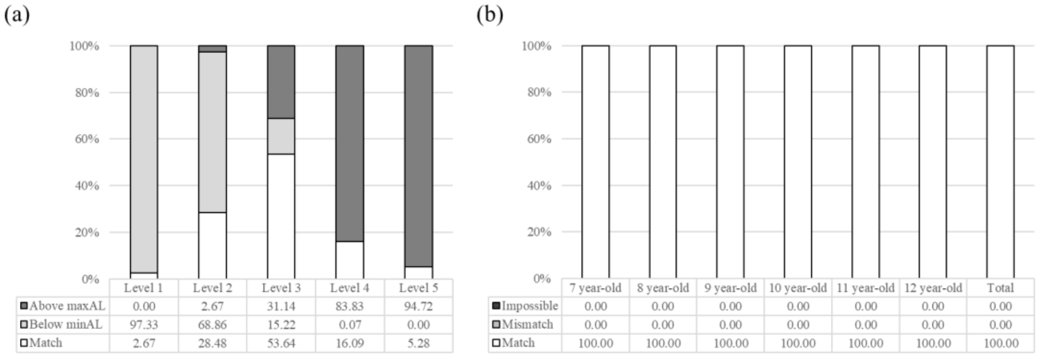


Figure 3.9 Degree of mismatch of new height system for chairs: (a) degree of mismatch for each level; (b) degree of mismatch by age

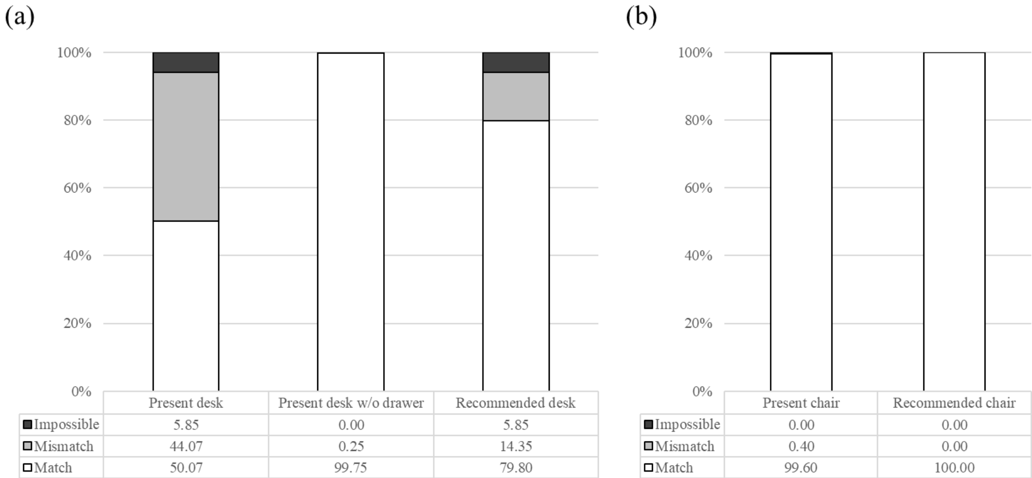


Figure 3.10 Comparison of present school furniture with recommended school furniture: (a) desk; (b) chair

3.4.3 Guideline for selection of recommended desk height

Providing adjustability has an inherent problem. Even if there is a desk and chair that could be adjusted to the recommended level of height for each person, it is irrelevant unless each person has the ability to select them. Although KSG-2010 includes a general instruction to evaluate whether the school furniture in use is anthropometrically well-matched or not, it isn't widely known to not only children but also their teachers. Moreover, it is not a quantitative method so it couldn't be a direct and exact method to select the recommended heights of desk and chair.

The recommended level of the SH could be decided by one of the anthropometric measures (PH). However, four anthropometric measures (ShH, EH, KH, PH) have to be measured to select the recommended DH level. Most of the people do not know them and they are not usually measured in schools. Therefore, if the recommended level of the DH could be predicted by a smaller number of anthropometric measures, it would be helpful in increasing the degree of matching in real-world situations. In this section, the recommended level of DH is predicted by S and PH using a multinomial logistic regression. In previous studies, S and PH were considered as critical anthropometric measures when deciding the dimensions of school furniture (Castellucci et al., 2015a; Cho, 1994; Hibaru and Watanabe, 1994; Molenbroek et al., 2003; Noro and Fujita, 1994; Roebuck et al., 1975). A dependent variable (recommended level) was created as follows: for each child, the level closest to the median of minAL and maxAL is a recommended level. The results of the multinomial logistic regression are listed in Table 3.2. The classification accuracy was 75.2%. However, 93.6% of the children are able to choose the recommended levels, considering the children to which the predicted recommended level is not closest to the median of minAL and maxAL but could be matched. With the exception of the children who did not have a matched level among the seven levels, all the remaining 79.80% of the children are able to choose the recommended level.

Table 3.2 Results of multinomial logistic regression

Predictor		B	SE	Wald	df	Sig.	Exp(B)	95% C.I. for Exp(B)	
								Lower Bound	Upper Bound
Level 1	Constant	536.476	13.806	1,509.855	1	0.000			
	S	-0.232	0.008	933.090	1	0.000	0.793	0.781	0.805
	PH	-0.663	0.023	814.565	1	0.000	0.515	0.492	0.539
Level 2	Constant	430.517	11.519	1,396.830	1	0.000			
	S	-0.179	0.006	883.141	1	0.000	0.836	0.826	0.846
	PH	-0.527	0.020	722.922	1	0.000	0.591	0.568	0.614
Level 3	Constant	347.118	10.083	1185.138	1	0.000			
	S	-0.140	0.005	743.140	1	0.000	0.869	0.861	0.878
	PH	-0.424	0.017	620.054	1	0.000	0.655	0.633	0.677
Level 4	Constant	271.648	8.711	972.512	1	0.000			
	S	-0.112	0.004	622.569	1	0.000	0.894	0.887	0.902
	PH	-0.308	0.014	485.439	1	0.000	0.735	0.715	0.755
Level 5	Constant	193.768	7.437	678.816	1	0.000			
	S	-0.081	0.004	450.635	1	0.000	0.922	0.915	0.929
	PH	-0.201	0.011	317.940	1	0.000	0.818	0.800	0.836
Level 6	Constant	102.229	5.790	311.722	1	0.000			
	S	-0.042	0.003	208.396	1	0.000	0.958	0.953	0.964
	PH	-0.100	0.008	142.309	1	0.000	0.905	0.890	0.920

Note. The reference category is level 7; Overall model evaluation (Likelihood ratio test): $\chi^2(12) = 10360.735$; $p < .001$; Cox & Snell $R^2 = 0.924$; Nagelkereke $R^2 = .945$; % correct classification = 72.6%

3.5 Conclusion

This study analyzed the anthropometric mismatch of the desks and chairs used in Korean primary schools by focusing on their height. The anthropometric measures of 4,014 children between the ages of 7 and 12 years were used in the analysis. As a result, only 50% of the children matched at least one level among the seven levels of present desks. The major causes of mismatch were excessively thick drawers and the improper design of height levels. Further analysis revealed that removing the drawers could lead to 99.60% of matching, and a change in the height of each of the seven levels could lead to 79.80% of matching. In case of the height system of the present chairs, it was found that the system had redundant levels though it showed a degree of match close to 100%. Further analysis confirmed that it was possible to match all children with five levels. Finally, to solve the practical problem of choosing a suitable desk height for an individual, the recommended level of desk height was estimated by the stature and popliteal height using multinomial logistic regression. The results revealed that 92.5% of the children could select acceptable level of desk height.

However, the results may not be consistent to those obtained by the anthropometric data of the entire population of children. In addition, the algorithmic approach, which suggested new height systems for the desk and chair, is a method of efficiently approximating an optimal set of height levels. Therefore, the suggested height systems of the desk and chair may not be the optimal systems.

Despite such limitations, the anthropometric data used in this study is quite large; therefore, the results of this study are still expected to contribute to the improvement of school furniture. Moreover, it is expected that suggested guideline helps students select and use a suitable desk and chair. In particular, training and encouraging students and their teachers to follow the guideline must be accompanied to overcome inherent problem of using adjustable furniture. Additionally, the algorithmic approach, which was adopted in this study to develop new height systems, can also be applied to the development of size systems for other products, when a large amount of anthropometric data can be acquired.

Chapter 4

Evaluation of the guidelines and children's ability to select the anthropometrically recommendable height of school furniture

4.1 Introduction

Today, sedentary activities are very common in children and long-term sitting of children can be observed frequently. Incorrect long-term sitting may lead to the occurrence of musculoskeletal disorders such as spinal diseases (Pynt et al., 2001; Takemitsu et al., 1988). Childhood is an especially important period for the formation of postural habits and the habits formed are difficult to correct in adulthood (Yeats, 1997). Moreover, spinal diseases in childhood could negatively affect physical development (Tanner et al., 1976). Therefore, it is very important to encourage children to sit appropriately.

Most children spend a significant time in school where many sedentary activities are held (Kumar, 1994; Troussier et al., 1999) so the establishment of sitting postural habits can be strongly affected by their school life. Additionally, participating in a lesson with an inappropriate posture can negatively affect learning performance (Smith-Zuzovsky and Exner, 2004). Consequently, schools have a tremendous responsibility in ensuring that children sit properly. In this context, schools have to offer an appropriate educational environment. More specifically, schools must offer anthropometrically designed school furniture to children. Use of school furniture that is not matched with the anthropometric characteristics of the user can lead to awkward posture (Afzan et al., 2012; Brewer et al., 2009; Castellucci et al., 2010; Cotton et al., 2002; Oyewole et al., 2010; Parcells et al., 1999). Desk and seat heights are known as especially critical dimensions (Lim et al., 2002; Tuttle et al., 2007). Agha (2010) found that children who use too high of a chair assumed awkward postures such as excessively leaning forward or positioning their feet between their hips and the seat. In addition, Panagiotopoulou et al. (2004) observed that children who use too high of a desk assumed poor postures such as sitting on the front edge of seat and shrugging their shoulders. Therefore, the height of school furniture for each child must be carefully determined by considering each child's anthropometric characteristics.

In Korea, all schools have to use desks and chairs that are certificated by the Korean Standards Association (KSA). KSG-2010 is a standard for chairs and tables for educational institutions such as kindergartens, elementary schools, junior high schools, and high schools (KSA, 2015). The corresponding international standard conforming to this standard is ISO 5970 (ISO, 1979). This standard regulates the size of school furniture to follow the given size system comprising seven levels. More specifically, furniture dimensions of each level must be in a given range or just meet a given fixed value. Something to note is that desk height and seat height are the only dimensions that have to be a fixed value by level. Most Korean primary schools have these seven types of desks and chairs to accommodate as many children as possible. Recently, in accordance with the suggestions from many researchers (Bendak et al., 2013; Panagiotopoulou et al., 2004; Parcells et al., 1999), adjustable desks and chairs in which the height can be incrementally adjusted to one of seven levels have also been widely used.

However, the spread of desks and chairs of various sizes still leaves the problem of whether children can choose a desk and chair of the right size for themselves. This problem is unavoidable because there are no one-size-fits-all solutions for school furniture design (van Niekerk et al., 2013; Yanto et al., 2017). To solve this problem, some guidelines to select the appropriate desk and seat heights should be given to children. If such guidelines are not given, children have to select by themselves. However, most children do not know their anthropometric measures, making it difficult for them to select the desk and chair of appropriate heights. KSG-2010 recommends that children select the levels of desk and seat heights based on their height. In other words, it suggests comparing their stature to the reference stature of each level and choosing the level of reference height nearest to their stature. However, the feasibility of this guideline is doubtful. First, the reference stature at each level is composed of equal intervals. This is in contrast with the ISO 5970 standard and the suggested guidelines in previous studies that were developed to decrease the degree of mismatch for children from other countries (Carneiro et al., 2017; Molenbroek et al., 2003). In addition, although desk height and seat height are related to independent anthropometric measures (Carneiro et al., 2017; Castellucci et al., 2010; Ramadan, 2011), the reference stature for each level of desk height and seat height is the same. Yanto et al. (2017) found that the use of a set with the same levels of desk and chair lead to a mismatch problem.

This study aims to evaluate the feasibility of currently used guidelines for selecting desk and seat heights of Korean primary school children and the ability of children to select the appropriate desk and seat heights without guidelines. In study 1, the degree of mismatch caused by following the guidelines was analyzed based on anthropometric data from Korean children. In study 2, a desk and seat height selection experiment was conducted and a mismatch analysis was performed. Finally, new guidelines were developed using classification algorithms to decrease the degree of mismatch.

4.2 Methods

4.2.1 Study 1: Evaluation of currently used guidelines for the selection of desk and seat heights

4.2.1.1 Currently used height systems and guidelines for school furniture

As mentioned above, both desks height (DH) and seat height (SH) can be adjusted over seven levels (Table 4.1). In particular, all desks have a drawer that is attached underneath the desktop. Subsequently, the underneath desk height (UDH) at each level depends on the board (desktop) thickness (BT) and the drawer height (DRH). In this study, it was assumed that BT is 20 mm and DRH is 70 mm, which are average values of desks used in Korean primary schools. To help children use anthropometrically appropriate school furniture, KSG 2010 proposed guidelines to select the level of DH and SH by referring to the child's stature (Table 4.1).

Table 4.1 Height systems for school furniture in Korea

Furniture dimensions	Set size						
	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**	**Level 7**
Stature (mm)	900	1050	1200	1350	1500	1650	1800
Desk height (mm)	400	460	520	580	640	700	760
Underneath desk height* (mm)	310	370	430	490	550	610	670
Seat height (mm)	220	260	300	340	380	420	460

Note. Underneath desk height of each level was defined under the assumption of board thickness and drawer height

4.2.1.2 Anthropometric data

This study employed anthropometric data measured by the national anthropometric survey (6th Size Korea, KATS) in 2010. In this study, five anthropometric measures for children aged from 7 to 12 (n = 2005) were selected: popliteal height, sitting (PH); knee height, sitting (KH); shoulder height, sitting (ShH); elbow height, sitting (EH); and stature (S) (Figure 4.1). The descriptive statistics of the five anthropometric measures of the children are presented in Table 4.2.

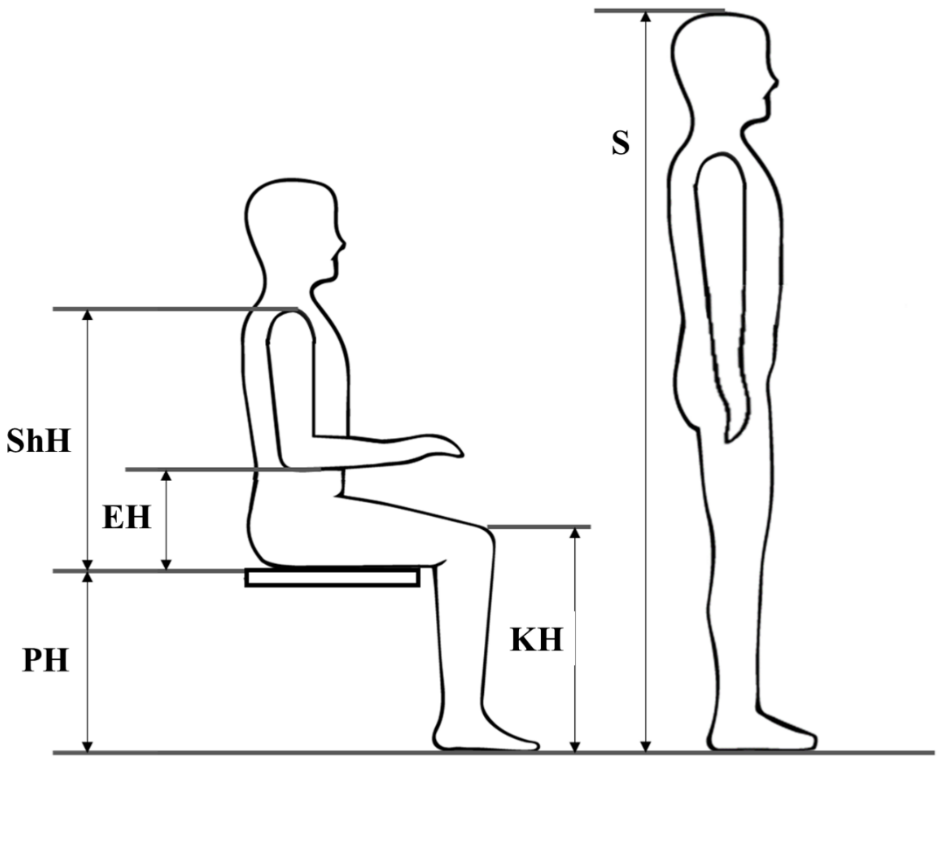


Figure 4.1 Selected anthropometric measures in study 1

Table 4.2 Anthropometric measures of Korean children

Age	Descriptive statistics	S (mm)	ShH (mm)	EH (mm)	KH (mm)	PH (mm)
7 (n = 171)	5th	1126.80	375.60	153.00	327.60	269.60
	50th	1231.00	411.00	178.00	374.00	305.00
	95th	1295.80	447.80	205.40	390.00	328.40
	Mean	1227.03	410.88	177.88	370.45	303.30
	SD	47.595	20.504	15.206	18.386	16.683
8 (n = 213)	5th	1201.00	400.00	160.00	360.40	288.70
	50th	1265.00	423.00	182.00	384.00	309.00
	95th	1386.60	469.30	213.30	431.60	348.30
	Mean	1276.00	428.25	184.03	387.26	312.64
	SD	53.889	21.574	16.023	19.342	18.137
9 (n = 250)	5th	1236.00	408.00	162.55	371.10	298.55
	50th	1358.00	455.00	192.50	418.00	334.00
	95th	1426.90	495.35	223.45	444.45	363.45
	Mean	1343.48	450.97	191.90	411.73	332.13
	SD	61.636	25.456	18.549	24.859	19.596
10 (n = 356)	5th	1292.00	426.85	169.00	387.00	314.85
	50th	1396.50	465.00	194.00	435.00	347.00
	95th	1493.15	511.00	230.00	472.15	382.15
	Mean	1395.20	465.99	195.27	433.17	347.88
	SD	54.943	23.893	17.996	22.145	18.837
11 (n = 475)	5th	1350.00	443.00	174.00	414.80	330.00
	50th	1442.00	481.00	202.00	445.00	358.00
	95th	1570.20	530.00	233.00	496.20	401.00
	Mean	1451.01	484.28	203.17	450.82	361.36
	SD	68.645	28.217	18.156	24.711	21.253
12 (n = 540)	5th	1406.20	459.10	180.00	434.10	344.10
	50th	1534.00	514.00	213.00	477.00	380.00
	95th	1635.90	560.00	250.90	510.00	414.90
	Mean	1529.01	513.04	213.60	473.93	378.95
	SD	70.296	30.474	21.004	25.573	21.920
Total (n = 2005)	5th	1223.35	406.00	165.00	370.00	297.00
	50th	1410.00	470.00	198.00	439.00	350.00
	95th	1595.00	544.00	237.00	499.65	402.00
	Mean	1411.06	472.43	198.99	435.45	349.95
	SD	116.288	42.169	21.813	41.060	32.198

4.2.1.3 Mismatch analysis

For every child, the lower and upper limits for SH, DH, and UDH can be calculated based on anthropometric measures (Afzan et al., 2012; Agha, 2010; Gouvali and Boudolos, 2006). For SH, both lower and upper limits were defined by PH:

$$(\mathrm{PH}+20)\cos 30° \leq \mathrm{SH} \leq (\mathrm{PH}+20)\cos 5°. \tag{1}$$

This equation means that the knee joints must be in an appropriate range (5° to 30° flexion) while the child is sitting on a chair. Note that 20 mm was added to PH to correct for the thickness of shoe sole in Equation (1). The appropriate range of knee joints was suggested by Molenbroek et al. (2003).

For DH, both lower and upper limits were defined by three anthropometric measures, EH, PH, and ShH:

$$\mathrm{EH}+[(\mathrm{PH}+20)\cos 30°] \leq \mathrm{DH} \leq (0.8517\mathrm{EH})+(0.1483\mathrm{ShH})+[(\mathrm{PH}+20)\cos 5°]. \tag{2}$$

This equation means that the shoulder joints must be in an appropriate range (0° to 25° flexion and 0° to 20° abduction) when the child is resting his or her elbows on the desk while sitting on a chair with appropriate SH. The appropriate range of shoulder joints was suggested by Parcells et al. (1999). For UDH, the lower limit was defined by KH and the upper limit was expressed by EH, PH, and ShH:

$$(\mathrm{KH}+20)+20 \leq \mathrm{UDH} \leq (0.8517\mathrm{EH})+(0.1483\mathrm{ShH})+[(\mathrm{PH}+\mathrm{ST})\cos 5°]-90. \tag{3}$$

This equation means that sufficient clearance (20 mm) between the child's legs and the bottom of the desk must be given while the child is sitting on a chair. Note that 20 mm was added to KH for the same reason as for the mismatch equation for SH. The upper limit of UDH was defined based on the upper limit of DH and the assumed height of the drawer and thickness of the desktop.

Finally, by considering the relationship between DH and UDH,

$$\mathrm{DH} = \mathrm{UDH} + 90, \tag{4}$$

mismatch equations for DH (Equation (2)) and UDH (Equation (3)) were merged to give

$$\max(\mathrm{EH} + [(\mathrm{PH} + 20)\cos 30°], (\mathrm{KH} + 20) + 20 + 90) \leq \mathrm{DH}$$
$$\leq (0.8517\mathrm{EH}) + (0.1483\mathrm{ShH}) + [(\mathrm{PH} + 20)\cos 5°]. \tag{5}$$

To evaluate the feasibility of the currently used guidelines, the degree of mismatch caused by following the guidelines was calculated. Every child was allocated to one of seven levels of SH and DH based on the guidelines (Table 4.1). In other words, each child was paired with levels of SH and DH for which the standard stature is closest to his or her stature. Next, whether or not the child and SH and DH are anthropometrically matched was determined based on Equations (1) and (4), respectively. If they were mismatched, it was verified whether the cause of the mismatch was exceeding the upper limit or falling short of the lower limit. Based on this mismatch analysis, degrees of mismatch for all children and by age group were calculated.

4.2.2 Study 2: Survey of voluntary mismatch of desk and seat heights

4.2.2.1 Participants

In study 2, 36 healthy 7- to 12-year-old children (18 boys and 18 girls) were recruited. Their average age was 9.53 (standard deviation (SD) = 2.00). A body discomfort chart and a visual analog scale were used to screen the unhealthy participants, and all of participants passed. Before data collection, the participants were informed by their caregivers of the purpose of the study and procedure, and they were given consent to participate. All participants received monetary compensation. The anthropometric information of the participants is given in Table 4.3.

Table 4.3 Anthropometric measures of children participating in study 2

Anthropometric posture	Anthropometric dimensions	Mean	SD	Min.	Max.
Standing	Stature (mm)	1422.21	110.42	1182.00	1695.00
	Weight (kg)	39.45	10.33	21.30	62.40
Sitting	Shoulder height (mm)	475.00	37.26	404.00	569.00
	Elbow height (mm)	196.64	19.79	153.00	232.00
	Knee height (mm)	429.36	40.63	347.00	510.00
	Popliteal height (mm)	366.31	36.64	292.00	455.00
	Buttock-Popliteal length (mm)	404.48	44.13	290.00	502.00
	Hip width (mm)	298.21	37.76	200.00	366.00

4.2.2.2 Equipment

For the experiment, a desk used in one Korean preliminary school and a chair with a footrest were prepared (Figure 4.2). For the chair, the height of the footrest and the seat were independently and continuously adjustable so that the effective seat height (the height of seat minus the height of the footrest) was freely adjustable. Also, the backrest was fully adjustable, allowing for effective seat depth (distance from the back to the front of the sitting surface) to be freely adjustable. The seat width of the chair was 470 mm, which was a factor of >1.1 greater than the maximum value of the buttock–popliteal length among the recruited children, so all participants were able to sit stably (Dianat et al., 2013; Gouvali and Boudolos, 2006; van Niekerk et al., 2013). For the desk, seven levels of adjustment were allowed but the desk height was fixed to level 7 (760 mm). Participants were free to adjust the effective desk height (height of the desk minus the height of the footrest) regardless of the fixed desk height because the heights of the footrest and the seat could be independently and continuously adjusted.

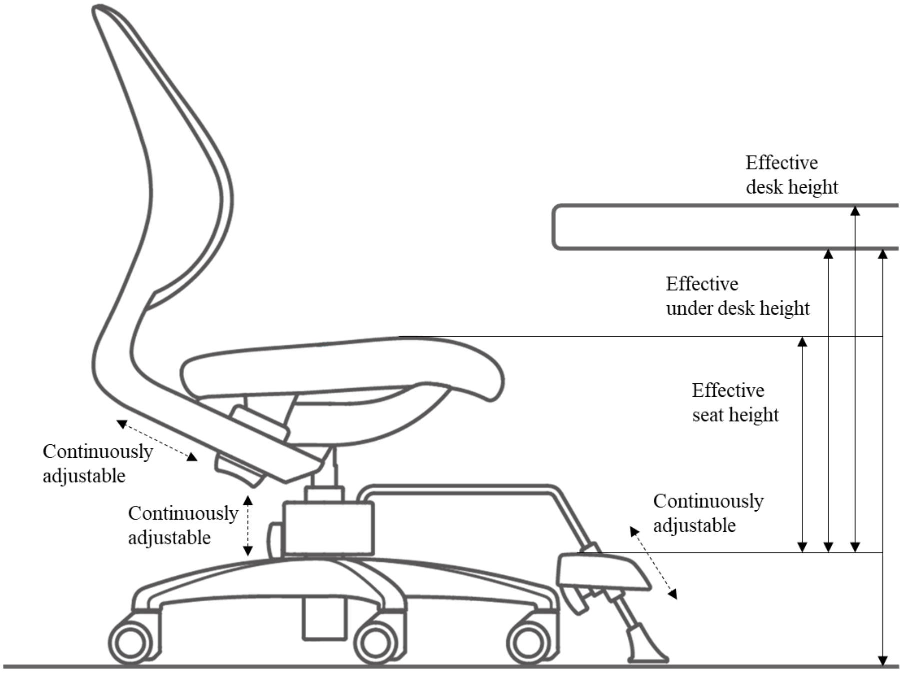


Figure 4.2 Illustration of equipment and measured dimensions in study 2

4.2.2.3 Experimental procedure

Prior to the experiment, seven body dimensions in relation to the dimensions of desk and seat for each participant along with their stature and weight were measured. Based on the measured dimensions, the back rest was adjusted and securely fixed so that the effective seat depth could fall within a recommendable range of 80% to 95% of buttock–popliteal length

(Afzan et al., 2012; Agha, 2010; Batistao et al., 2012; Chung and Wong, 2007; Gouvali and Boudolos, 2006; Jayaratne, 2012). First, in the experiment, the footrest height was adjusted to determine the effective seat height suitable for each participant. Second, the participants were seated in front of the desk and asked to determine the appropriate seat height for themselves for the given desk height. At the same time, the initial footrest and seat heights were set either very high or very low, preventing participants from selecting the initial seat height. Once the participants confirmed the final heights, the effective desk and seat heights were measured. There was no time limit set for participants to select their own settings and they were allowed to override their previous decision until they made a final decision.

4.2.2.4 Mismatch analysis

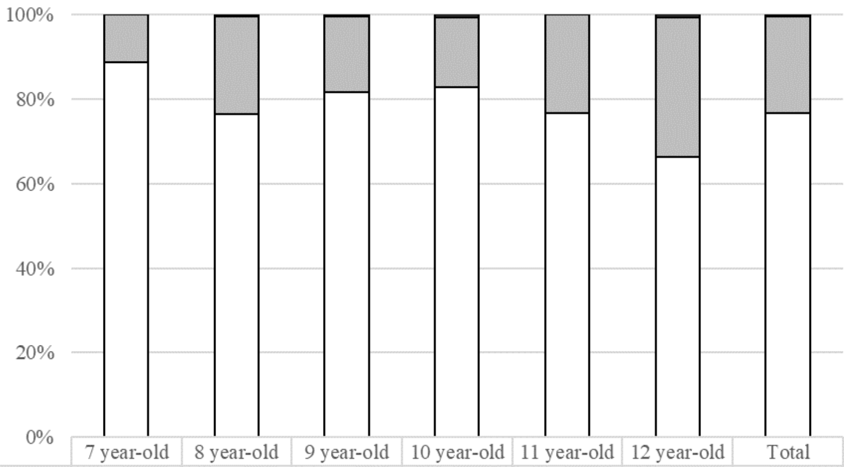
As in study 1, the frequencies of match, mismatch from an excess of the upper limit, and mismatch from a shortfall of the lower limit were calculated based on the effective desk and seat heights chosen by participants.

4.3 Results

4.3.1 Degree of mismatch caused by following the currently used guidelines

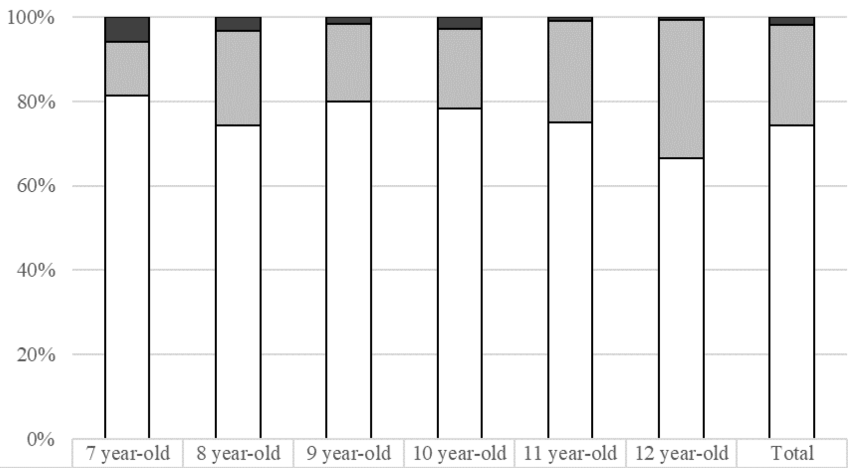
Based on the mismatch analysis, all children were able to match with one of five DH levels (levels 2, 3, 4, 5, and 6). However, mismatching cases did occur when following the guidelines. When participants followed currently used guidelines, the degree of DH mismatch is shown in Figure 4.3. A total of 76.62% of children from 7 to 12 years in age matched well; however, 23.03% mismatched because the paired level was too high for them while 0.35% paired to too low a level. In terms of age groups, the 12-year-old group was the most mismatched group. For 7-year-old children, 88.89% matched well, while 11.11% paired at too high a level for them. For 8-year-old children, 76.53% were paired with well-matched levels but 23.00% and 0.47% were paired with too high a level and too low a level, respectively. For 9-year-old children, 81.60% matched well while 18.00% and 0.40% could not be matched because too high and too low levels were paired. For 10-year-old children, 82.87% matched well, while 16.57% of them paired with too high a level and 0.56% paired with too low a level. For 11-year-old children, 76.63% of them matched and 23.37% of them could not be matched because too high a level was paired. Finally, for 12-year-old children, 66.36% paired with well-matched levels while 33.09% mismatched by too high a level and 0.55% mismatched by too low a level.

For SH, mismatching cases also did occur when the children followed the guidelines, although Based all children were able to match with one of five SH levels (levels 2, 3, 4, 5, and 6). The results of the SH mismatch analysis is shown in Figure 4.4. A total of 74.38% of children from 7 to 12 years in age matched well. However, 23.68% mismatched because the paired level was too high for them while 0.35% paired with too low a level. In terms of age groups, the 12-year-old group was the most mismatched group, as was the case for DH. For 7-year-old children, 81.29% matched well while 12.87% paired with too high a level and 5.85% paired with too low a level. For 8-year-old children, 74.18% were paired with well-matched levels but 22.54% and 3.29% were paired with too high a level and too low a level, respectively. For 9-year-old children, 80.00% matched well while 18.40% and 1.60% were paired with too high a level and too low a level, respectively. For 10-year-old children, 78.37% matched well while 18.82% of them paired with too high a level and 2.81% paired with too low a level. For 11-year-old children, 74.95% of them matched well while 24.21% of them could not be matched because too high a level was paired and 0.84% mismatched because too low a level was paired. Finally, 66.54% of 12-year-old children paired with well-matched levels while 32.72% mismatched by too high a level and 0.74% mismatched by too low a level.



	7 year-old	8 year-old	9 year-old	10 year-old	11 year-old	12 year-old	Total
■ Too low DH is selected	0.00	0.47	0.40	0.56	0.00	0.55	0.35
▨ Too high DH is selected	11.11	23.00	18.00	16.57	23.37	33.09	23.03
□ Matched	88.89	76.53	81.60	82.87	76.63	66.36	76.62

Figure 4.3 Results of mismatch analysis for desk height in study 1

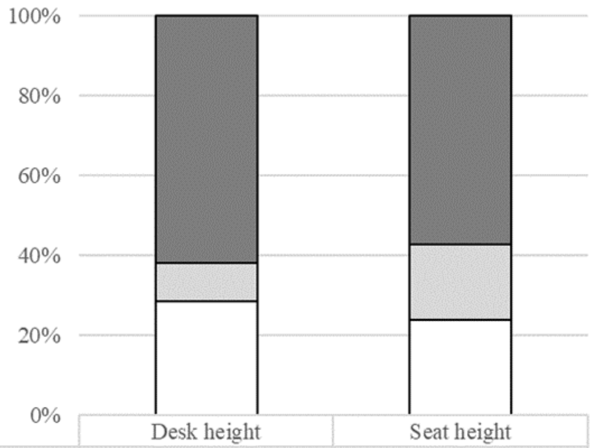


	7 year-old	8 year-old	9 year-old	10 year-old	11 year-old	12 year-old	Total
Too low SH is selected	5.85	3.29	1.60	2.81	0.84	0.74	1.94
Too high SH is selected	12.87	22.54	18.40	18.82	24.21	32.72	23.68
Matched	81.29	74.18	80.00	78.37	74.95	66.54	74.38

Figure 4.4 Results of mismatch analysis for seat height in study 1

4.3.2 Degree of mismatch caused by preference

The degrees of mismatch of both desk and seat heights were 71.43% and 76.19%, respectively (Figure 4.5). For desks, 61.90% of children selected a DH value exceeding the upper limit, while 9.52% selected a DH value falling short of their lower limit. For chairs, 57.14% selected heights exceeding their upper limit and 19.05% selected heights falling short of their lower limit.



	Desk height	Seat height
Too high height is selected	61.90	57.14
Too low height is selected	9.52	19.05
Matched	28.57	23.81

Figure 4.5 Results of mismatch analysis for desk and seat heights in study 2

4.4 Discussion

4.4.1 Mismatch problem in Korean primary schools

The results of these two studies revealed that the current guidelines were designed improperly, and, moreover, children lacked the ability to select the appropriate furniture height. Previously, Lim et al. (2002) investigated the usage behavior of school furniture in one Korean school and found that 64% of students did not use the school furniture recommended by the guidelines. They also confirmed that 74% did not know the guidelines. Taken together, these results indicate that usage behavior of school furniture in Korean primary schools may be problematic.

According to the result of study 1, about three quarters of children were able to select appropriate DH and SH by following the currently used guidelines. Such results could be explained by a change in the anthropometric characteristics of Korean children. It has been over 17 years since the last revision of KSG-2010 on furniture dimensions. Moreover, this revision was based on anthropometric data acquired in 1998. The secular trend of anthropometric characteristics of children has been observed in other countries (Castellucci et al., 2015b; Fredriks et al., 2000; Gutiérrez and Apud, 1992). Castellucci et al. (2015b) argued that the secular trend can lead to a temporal change of accommodation level for long-lifetime products. In mismatched cases for both DH and SH, most of them were caused by pairing with too high a level. Based on these results, it can be inferred that the standard stature for each level needs to be increased.

In study 2, <30% of participants selected the appropriate desk and seat heights for themselves. Also, most students selected desk and seat heights that exceeded the upper limit. The first possible cause of such results may be the difference in the possible range to adjust in a natural situation. The desk height cannot be set significantly lower than the lower limit because there are limitations to setting the desk height lower than a certain height to position one's legs under the desk. However, it can be set significantly higher than the upper limit owing to fewer limitations but broader adjustable ranges, leading to a higher probability of mismatch exceeding the upper limit. For chair height, the range from the upper limit to the physically adjustable upper limit is broader than the range from the lower limit to the physically adjustable lower limit as well. Second, these results could be affected by the preference of children. Tuttle et al. (2007) found that students preferred higher seat height when they used desks with a high desk height. They also confirmed that preferred seat height is negatively correlated with stature. These results indicate that children who selected excessively high DH as the recommendable DH were likely to select too high an SH value for themselves and children who are generally shorter than middle and high school students may prefer high SH. Lastly, children lack experience with desks and chairs designed specifically for their anthropometric dimensions. Except for school furniture, most furniture/products are designed to fit the dimensions of adults. Children who lack knowledge of appropriate posture and furniture selection criteria or children who lack experience with musculoskeletal disease or back pain may have been used to using inappropriately designed furniture or may not even realize that they are feeling discomfort. Such behaviors have been reported by Panagiotopoulou et al. (2004). They revealed that most children from three primary schools in Greece were using mismatched desk and chair heights, all of which were too high. In addition, it was investigated that such an issue leads to awkward postures such as sitting on the edge of a seat or lifting arms and hunching shoulders. However, according to the survey of subjective perception, only a relatively small percentage of students felt uncomfortable with their desk height and seat height. Also, such a tendency occurs more frequently with children of younger age. These findings indicate that following the wrong guidelines may affect voluntary selection of the wrong furniture dimension.

4.4.2 Development of new guidelines to select recommended desk and seat heights

As shown in the results of studies 1 and 2, even if there is a desk and a chair that can be adjusted to suitable heights for each person, this is meaningless if wrong guidelines are given or each person has the ability to choose them. The recommended level of SH can be decided by a single anthropometric measure (PH). However, four anthropometric measures (ShH, EH, KH, and PH) have to be measured to select the recommended level of desk height. Most people do not know these values; moreover, they are difficult to measure in school (Noro and Fujita, 1994). Therefore, a practical and easy method to select the appropriate desk height is needed.

In this section, new guidelines are derived by using multinomial logistic regression (MNL) and decision tree (DT) analysis using stature as an input variable, because stature is referred to as critical dimension for anthropometric school furniture design (Roebuck et al., 1975). Although there have been some studies indicating that PH is the most relevant anthropometric measure (Castellucci et al., 2015a; Molenbroek et al., 2003; Noro and Fujita, 1994), stature was selected as an input variable because it is the most familiar and easily measurable anthropometric measure for children. Given that children could be matched to multiple levels, the true recommended levels of DH and SH for each child were assigned as follows: The level closest to the median of the lower and upper limits was assigned as the true recommended level. A randomly selected sample of 80% of the data was used as a training set and the remaining data were used as a test set.

The results are listed in Table 4.4 and Table 4.5. The recommended range of stature for levels 1 and 7 could not be derived because there was no child whose true recommended level was level 1 or 7. For DH, the classification accuracy of MNL was 0.905. A total of 92.62% of the children were able to choose the recommended levels, given that the predicted recommended level was not a true recommended level but still anthropometrically acceptable. The classification accuracy of DT was 0.91, and 92.42% of the children were able to choose an acceptable level. For SH, the classification accuracy of both MNL and DT was 0.827. A total of 90.03% of the children were able to choose the acceptable levels by using the new guidelines based on the results of MNL, while the matching rate for the new guidelines based on the DT results was 90.33%. The results revealed that the matching rate could be increased by suing the new guidelines. The accuracies and matching rates of the two new guidelines had no significant difference, so it was difficult to distinguish superiority between the new guidelines. However, given that the matching rate of the entire population might be slightly different from the results in this study, the new guidelines based on DT that showed better classification performance can be recommended.

Table 4.4 Comparison of currently used and new guidelines for DH

Guidelines	Range of stature (mm)							Matching rate (%)
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	
Currently used guide line	- 974 (900)	975 - 1124 (1050)	1125 - 1274 (1200)	1275 - 1424 (1350)	1425 - 1574 (1500)	1575 - 1724 (1650)	1725 - (1800)	76.62
New guideline based on MNL	N/A	- 1145	1146 - 1311	1312 - 1470	1471 - 1639	1640 -	N/A	92.62
New guideline based on DT	N/A	- 1150	1151 - 1313	1314 - 1469	1470 - 1616	1617 -	N/A	92.42

Table 4.5 Comparison of currently used and new guidelines for SH

Guidelines	Range of stature (mm)							Matching rate (%)
	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	
Currently used guide line	- 974 (900)	975 - 1124 (1050)	1125 - 1274 (1200)	1275 - 1424 (1350)	1425 - 1574 (1500)	1575 - 1724 (1650)	1725 - (1800)	74.38
New guideline based on MNL	N/A	- 1144	1145 - 1309	1310 - 1481	1482 - 1654	1655 -	N/A	90.03
New guideline based on DT	N/A	- 1163	1164 - 1314	1315 - 1475	1476 - 1626	1627 -	N/A	90.33

4.5 Conclusion

In this study, we evaluated the feasibility of currently used guidelines for the selection of desk and chair height levels. Anthropometric data from 2005 Korean children were acquired and a mismatch analysis was conducted. The results reveal that a quarter of children were mismatched when they were paired with the height level recommended by the guidelines. In most mismatched cases, children were paired with too high a height level, even though they could be matched with one of the lower height levels. It was also found through the experiment that most children by themselves select desk and seat heights that are too high. To decrease the degree of mismatch, new guidelines were suggested by using classification algorithms. Evaluation the results on using the new guidelines revealed that they could increase the degree of match significantly.

Although the new guidelines were effective, they must be accompanied by action if they are to be meaningful. Therefore, first, it is important to encourage children to follow the guidelines through training and to familiarize them with anthropometrically recommendable school furniture. Secondly, a wider spread of adjustable school furniture is needed to mitigate the mismatch problem. Furthermore, they should be adjustable more easily than they are at present. A type of most of currently used height adjustable school furniture is a set-up type. More specifically, height adjustable desks and chairs for Korean primary schools have telescopic legs. They have seven holes in the legs so the height could be fixed to one of seven levels using Allen screw. This type of adjustable school furniture has economical advantage but it needs considerable disruption to adjust once it assembled. Thus, it is recommended to offer children more easily adjustable school furniture such as pneumatic or electric adjustable desks and chairs. At last, considering that primary school children experience relatively rapid physical development, stature needs to be measured at least once a year and it needs to be checked regularly whether their school furniture heights are appropriate or not.

The results of this study may change if more anthropometric data are acquired in study 1 or if experimental data from more children are gathered in study 2. However, they are still meaningful for identifying the mismatch problem caused by giving children multiple choices. Furthermore, a significant improvement in the degree of matching could be expected if the new guidelines are offered to children. The aim of this study was to evaluate and improve the guidelines for the selection of school furniture height, but it was not focused on devising guidelines for the design of school furniture. Further research needs to be conducted to evaluate the validity of the height system suggested by KSG-2010.

Chapter 5

Development of real-time sitting posture monitoring system for children using pressure sensors

5.1 Introduction

Sedentary lifestyles are very common for modern people and it is considered important to maintain a good posture while sitting because inappropriate sitting postures may lead to musculoskeletal disorders (Christie et al., 1995; Pynt et al., 2001; Takemitsu et al., 1988). Proper sitting posture is especially important for children. The postural habits formed during childhood are likely to carry over to adulthood because these habits do not change easily once they are formed (Floyd and Ward, 1969; Yeats, 1997). Additionally, musculoskeletal disorders that develop during childhood are more dangerous than those that develop during adulthood. Back pain during childhood caused by improper posture can be a major risk factor for the development of lumbar diseases as growth occurs (Grimmer et al., 2006; Harreby et al., 1999). These diseases are difficult to treat once they develop and are likely to cause similar diseases in the future (Troup et al., 1987). Furthermore, they can be a deterioration factor for the physical development of children (Tanner et al., 1976). Therefore, it is important to form good postural habits during childhood.

To effectively encourage children to form good postural habits, it is desirable for posture observation and correction to be performed in real time. Traditionally, posture corrections have been made in such a way that human observers (ergonomic specialists, occupational therapists, teachers, parents, etc.) monitor a child’s sitting behavior, identify the causes of postural problems, and encourage the child to sit properly. However, this process has two major drawbacks. The first is a drawback of the observation method. This method requires significant time and resource investment, meaning it is difficult perform long-term observation. Additionally, reliability problems may arise because of variance between observers (Xu et al., 2013). The second drawback is a problem with the correction method. The effectiveness of this method may decrease over time because it is difficult for users to remember guidelines and maintain good posture. Zheng and Morrell (2013) postulated that real-time posture correction may be more effective for learning and maintaining good posture based on the results of interviews with ergonomic specialists and occupational therapists. Because of these problems, there is a need a system to monitor and correct posture automatically in real time.

In order to develop such a system, an automatic posture classification system is required to collect objective measurements from a subject and determine their posture. Such systems can be roughly divided into two types according to the conditions for sensing. The first is a type of system that observes posture by attaching various devices to the subject's body. For instance, sensors such as accelerometers, gyroscopes, or goniometers can be attached to the subject's body and directly measure their postures based on inertial measurements of body parts and joints (Ko et al., 2017; Wong and Wong, 2008; Worsley et al., 2017). Systems that use markers for motion capture also belong to this type (Korakakis et al., 2014; Kuo et al., 2009; O'Sullivan et al., 2010). In this type of system, it is possible to observe the posture of a subject accurately and without any complex data processing because of the directness of measurement. However, such systems are not usable in the real world because of their hardware complexity and natural motion inhibition. According to Fradet et al. (2011), such systems require careful selection of attachment points for sensors (or markers) to acquire accurate data, meaning users would require expert knowledge. Additionally, the attached sensors (or markers) could inhibit the natural movement of subjects (Choi and Park, 2015). The second type is systems that do not require any devices to be attached to a subject's body. Marker-less motion capture systems belong to this type. In such systems, a subject is filmed by a depth camera and RGB-camera, and the posture of the subject is calculated using a skeleton-tracking algorithm (Choi and Park, 2015; Harutyunyan et al., 2017; Hassani et al., 2017; Liu et al., 2017; Wiedemann et al., 2014). Based on recent developments in image processing technology, a system using only an RGB-camera has been developed (Sánchez et al., 2017). These systems do not physically limit the movement of subjects, meaning they allow more natural movement. However, these systems can still limit the natural behavior of subjects because they can give subjects a negative impression of being monitored, which also raises privacy concerns (Xu et al., 2013). Because of the drawbacks mentioned above, several attempts have been made to develop novel posture monitoring systems using pressure sensors (Lee and Shin, 2016; Meyer et al., 2010; Schrempf et al., 2011; Xu et al., 2013; Zemp et al., 2016b; Zheng and Morrell, 2013). These systems predict a subject's posture based on center of pressure, pressure distribution, etc. Such systems do not require any devices other than a chair with built-in sensors and do not physically or psychologically interfere with the movement of subjects, meaning they are suitable for use in the real world and enable observation of the natural behavior of subjects. However, because these systems do not directly measure body parts or joint positions, researches have struggled to identify optimal hardware configurations and analysis techniques with the goal of predicting more posture more accurately.

In previous studies, Tan et al. (2001) recruited adult subjects aged 18 to 60 years and obtained pressure data for a total of ten sitting postures. Commercial mat-type pressure sensors (consisting of a grid of 42 ×48 force-sensitive resistors (FSRs)) were attached to the seat pan and backrest of a chair. The obtained pressure distribution data were analyzed by PCA-based classification algorithms to predict sitting postures. Zemp et al. (2016b) performed a sitting posture prediction study on adults aged 24 to 64 years. A total of 16 FSRs were attached to the seat pan, backrest, and armrest of a chair. A total of seven sitting postures were predicted. In addition to pressure distribution data, they utilized backrest angle data captured by motion-modules equipped with accelerometers, gyroscopes, and magnetometers. Five different classification algorithms were applied to predict sitting postures: support vector machine, multinomial regression, neural network, random forest, and boosting. Chenu et al. (2009) predicted nine sitting postures with varying waist and hip positions. A total of twelve adult subjects participated and commercial mat-type pressure sensors (32×32 FSRs) were attached to the seat pan of a chair. Instead of using a machine learning technique, posture classification was performed based on the pre-mapped pressure distributions of each posture. Meyer et al. (2010) predicted a total of sixteen sitting postures using two different mat-type pressure sensors. One was a commercial sensor (32×32 FSRs) and the other was a custom-made sensor consisting of 240 FSRs. Compared to other related studies, they predicted a more diverse array of postures. A Naïve Bayes classifier was applied to classify the postures. Xu et al. (2013) developed a textile pressure sensor mat called the "eCushion," consisting of 256 sensors (16×16 FSRs), and attached it to the seat pan of a chair. They predicted seven postures using a dynamic time warping-based classification method. Zemp et al. (2016a) used a custom-made mat-type pressure sensor (8×8 FSRs) called the "SIT-CAT" to predict seven sitting postures. Adult subjects aged 25 to 57 years participated and the random forest method was applied as a prediction algorithm. Bao et al. (2013) attempted to predict sitting postures using fewer sensors by attaching only five FSRs to the seat pan of a chair. Five static postures and two activities (swaying and shaking) were selected for testing and a density-based clustering method was applied to classify the postures.

Previous studies predicted sitting postures using pressure data obtained by custom-made or commercial pressure sensors. The pressure sensors were typically attached to the seat pan of a chair and it can be reasonably assumed that the pressure distribution obtained from the seat pan is indispensable for predicting posture. For classification algorithms, researchers adopted various algorithms based on their hardware configurations and extracted input features. Although the number of predicted postures was different, most studies included an upright posture, leaning of the upper body in four directions (left, right, forward, backward), and postures for each foot crossing over the other. However, these studies had certain limitations. First, they acquired pressure data for selected postures, which are defined qualitatively. Considering the facts that each posture has intra-variability and the boundary of each posture is unclear, prediction results may be less reliable, even if the accuracy of classification is high. Second, these studies have mainly collected the data from adults. Even for the same posture, the pressure distributions of children may be different than those of adults. This is because children have distinctively different physical characteristics from adults in terms of body proportions, as well as the length, weight, and geometry of cervical vertebrae and joints (Straker et al., 2008a). According to Moes (2007), various parameters that determine pressure distributions are influenced by demographic and anthropometric characteristics, such as body mass, gender, stature, somatotype, and body fat percentage. It means that posture prediction systems developed for adults have limitations in reproducing the same performance when applied to children. Therefore, to develop a reliable system for predicting the postures of children, it is necessary to acquire data of qualitatively defined postures from children.

In this study, a mat-type pressure sensor was developed and inserted into the seat pan of a chair for non-invasive observation and pressure distribution data for pre-defined postures of children were collected. A convolutional neural network (CNN) model, which is a famous deep learning algorithm for image classification, was applied to classify sitting postures based on collected data and three independent experiments were performed considering three applicable usage scenarios: usage by familiar identifiable users, usage by familiar, but unidentifiable users, and usage by unfamiliar users.

5.2 Methods

5.2.1 Hardware configuration & measurement characteristics

In order to acquire the pressure distribution data for sitting postures, a conventional chair for children (RA-070SDSF, Duoback Korea, Seoul, Korea) was equipped with a customized sensing cushion containing a film-type pressure sensor (Figure 5.1). The chair could be adjusted for location of backrest, height of seat pan, and position of footrest to fit each participant's body size. The size of the sensor was 318×318 mm and it included 64 (8×8) FSRs (TechStorm, Seoul, Korea). The pressure distribution data was recorded at a 10-Hz frequency and 12-bit resolution. Because of limitations in the force sensitivity range of the sensors, pressure was measured by applying different amplification ratios and threshold values based on the weights of subjects. This process prevented data overflow and offset the differences in measured data between people with different weights when they assumed the same sitting posture. The data was transmitted to a smartphone (Galaxy Note 3, Samsung, Seoul, Korea) through a Bluetooth network using appropriate applications.

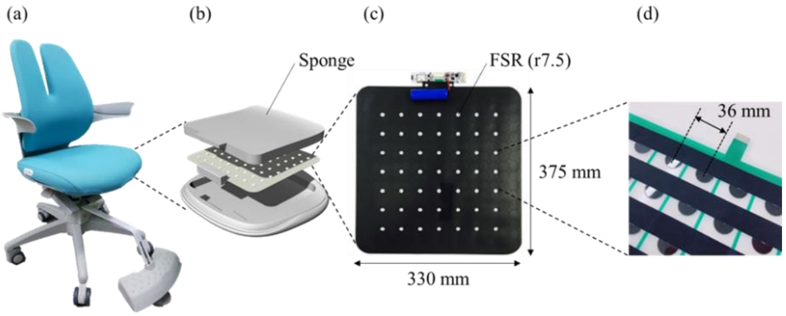


Figure 5.1 Hardware Configuration. (a) Chair with a sensing cushion, (b) Structure of sensing cushion, (c) Customized film-type pressure sensor inserted into sensing cushion, (d) Structure of sensor mat

5.2.2 Environment for data acquisition

For data acquisition, one chair with a sensor, one desk, two simple protractors, and two cameras were prepared for each participant. The pressure distribution data for each posture was measured while participants sat at the desk, which is used in Korean elementary schools. The protractors were installed to the right and rear of the participants to verify that they correctly assumed the prescribed posture. The cameras were installed to the left and front of the participants so that lateral and front views of the participants could be filmed. The dimensions of the environment are presented in Figure 5.2.

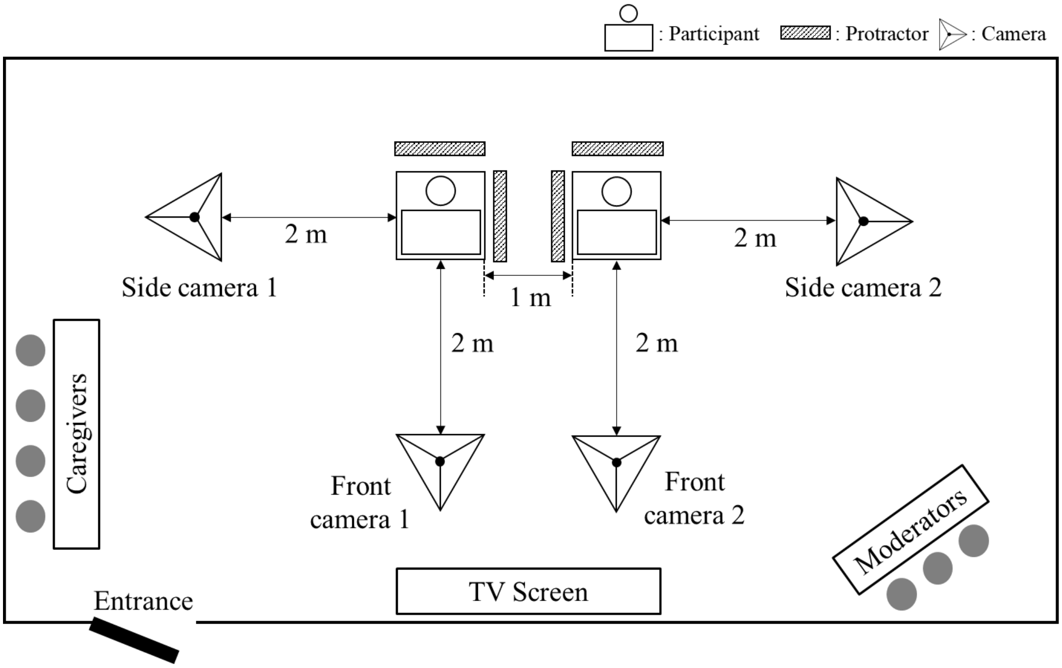


Figure 5.2 Data acquisition environment

5.2.3 Data acquisition

5.2.3.1 Participants

A total of 24 healthy 7 to 12 year-old children (11 boys, 13 girls) were recruited for data acquisition. Their average age was 10.13 years (SD = 1.62). A body discomfort chart and visual analogue scale were used to screen unhealthy participants (Kelly et al., 2009) and all participants passed. Prior to data collection, the participants and caregivers were informed regarding the purpose and procedure of the study, and they gave consent to participate. The anthropometric information of the participants is listed in Table 5.1.

Table 5.1 Anthropometric information of participants

Measuring posture	Anthropometric dimensions	Mean	SD	Min.	Max.
Standing	Height (mm)	1422.04	101.84	1182.00	1630.00
	Weight (kg)	40.45	10.06	21.30	56.00
Sitting	Height (mm)	729.88	44.08	641.00	817.00
	Shoulder height (mm)	477.46	32.33	417.00	550.00
	Elbow-seat height (mm)	196.96	20.09	153.00	226.00
	Knee height (mm)	431.50	37.23	347.00	502.00
	Popliteal height (mm)	366.42	31.01	292.00	422.00
	Buttock-Knee length (mm)	481.79	45.54	360.00	544.00
	Buttock-Popliteal length (mm)	406.83	42.38	290.00	455.00
	Buttock-Abdominal thickness (mm)	216.13	32.07	162.00	270.00
	Hip width (mm)	306.33	36.76	218.00	366.00

5.2.3.2 Postures

In this study, nine postures were selected considering the commonly predicted postures in previous studies (Bao et al., 2013; Chenu et al., 2009; Meyer et al., 2010; Tan et al., 2001; Xu et al., 2013; Zemp et al., 2016a; Zemp et al., 2016b) and commonly observed postures in Korean children (Figure 5.3): (a) good posture, (b) leaning forward, (c) leaning left, (d) right foot over left, (e) leaning right, (f) left foot over right, (g) sitting at the front edge, (h) slouching, (i) crossed-legs. To cover a wider range of postures, sub-postures were included in some of the selected postures. The good posture includes a slightly leaning backward posture and upright posture (Figure 5.3 (a)). The leaning forward posture includes a normally leaning forward posture and head down on the desk posture (Figure 5.3 (b)). The leaning left posture includes a normally leaning left posture, leaning left and forward posture, and leaning left and slouching posture (Figure 5.3 (c)). The right foot over left posture includes a right foot fully over left posture and right foot slightly over left posture (Figure 5.3 (d)). The leaning right posture includes a normally leaning right posture, leaning right and forward posture, and leaning right and slouching posture (Figure 5.3 (e)). The left foot over right posture includes a left foot fully over right posture and left foot slightly over right posture (Figure 5.3 (f)). The definition of each posture was specifically defined based on the position of body parts, such as the hips, upper body, and legs (Table 5.2). In particular, the definitions for the upper body and hip positions for each posture were established according to previous studies related to workload assessment of sitting work and anthropometric recommendations for the usage of chairs (Hignett and McAtamney, 2000; Keyserling et al., 1992; Openshaw and Taylor, 2006; Panagiotopoulou et al., 2004).

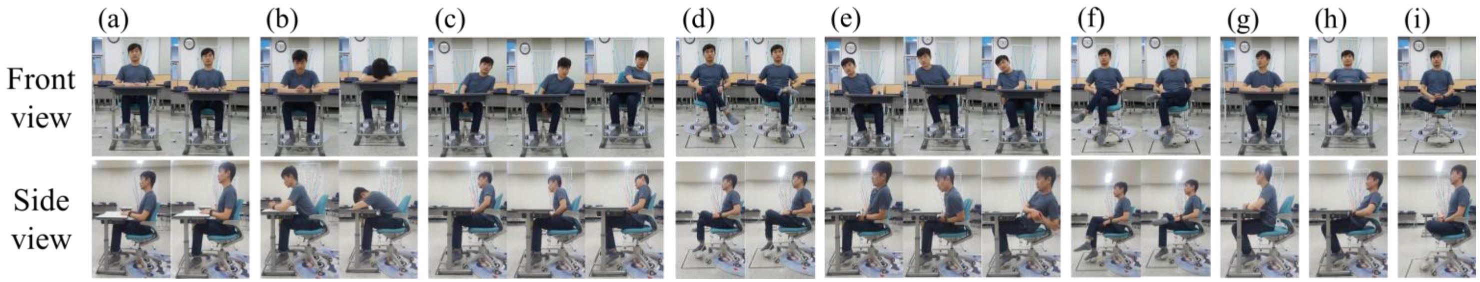


Figure 5.3 Front and side views of selected sitting postures. (a) good posture (left: slightly leaning backward posture, right: upright posture), (b) leaning forward posture (left: normally leaning forward posture, right: head down on the desk posture), (c) leaning left posture (left: normally leaning left, center: leaning left & forward posture, right: leaning left & slouching posture), (d) right foot over left posture (left: right foot fully over left posture, right: right foot slightly over left posture), (e) leaning right posture (left: normally leaning right posture, center: leaning right & forward posture, right: leaning right & slouching posture), (f) left foot over right posture (left: left foot fully over right posture, right: left foot slightly over right posture), (g) sitting at the front edge posture, (h) slouching posture, (i) crossed-legs posture

Table 5.2 Definitions of selected sitting postures

Selected posture	Included posture	Description	Posture discrimination criteria			
			Hip position	**Upper body position**	**Leaning on the backrest?**	**Leg position**
Good posture	Slightly leaning backward	A person leans slightly leaning backward comfortably. The back is well-supported by the backrest	80% ~ 95%	Extension: ~10° Left Lateral Bend: ~10° Right Lateral Bend: ~10°	Yes	Both thighs remain parallel to the ground
	Upright	A person puts both feet flat on the floor and is sitting upright comfortably. The back is not supported by the backrest	80% ~ 95%	Flexion: ~10° Left Lateral Bend: ~10° Right Lateral Bend: ~10°	No	Both thighs remain parallel to the ground
Leaning forward	Normally leaning forward	A person puts their arms on the desk and tilts their upper body forward to support it with the desk	80% ~ 95%	Flexion: 10°~	No	
	Head down on the desk	A person puts their arms on the desk while placing their head on the desk	80% ~ 95%	The upper body or head touches the desk or lower arm.	No	

Note. Hip position: The ratio of buttock-front tip length of seat to buttock popliteal length

Table 5.2 (Continued)

Selected posture	Included posture	Description	Posture discrimination criteria			
			Hip position	Upper body position	Leaning on the backrest?	Leg position
Leaning left	Normally leaning left	A person leans their upper body to the left only	80% ~ 95%	Flexion: ~10° Extension: ~10° Left lateral bend: 10°~	Yes	
	Leaning left & forward	A person leans their upper body to the left and forward	80% ~ 95%	Flexion: 10°~ Left lateral bend: 10°~	No	
	Leaning left & slouching	A person sits on the front part of the seat leaning their upper body to the left and backward against the backrest	~ 50%	Extension: 10°~ (*Extension until fully leaning against the back plate in the defined hip position) Left lateral bend: 10°~	Yes	
Right foot over left	Right foot fully over left	A person puts their right leg fully over their left leg	80% ~ 95%			Knees are touching
	Right foot slightly over left	A person puts their right leg slightly over their left leg	80% ~ 95%			Right ankle resting on left knee

Note. Hip position: The ratio of buttock-front tip length of seat to buttock popliteal length

Table 5.2 (Continued)

Selected posture	Included posture	Description	Posture discrimination criteria			
			Hip position	Upper body position	Leaning on the backrest?	Leg position
Leaning right	Normally leaning right	A person leans their upper body to the right only	80% ~ 95%	Flexion: ~10° Extension: ~10° Right lateral bend: 10°~	Yes	
	Leaning right & forward	A person leans their upper body to the right and forward	80% ~ 95%	Flexion: 10°~ Right lateral bend: 10°~	No	
	Leaning right & slouching	A person sits on the front part of the seat leaning their upper body to the right and backward against the backrest	~ 50%	Extension: 10°~ (*Extension until fully leaning against the back plate with the defined hip position) Right lateral bend: 10°~	Yes	
Left foot over right	Left foot fully over right	A person puts their left leg fully over their right leg.	80% ~ 95%			Knees are touching
	Left foot slightly over right	A person puts their left leg slightly over their right leg.	80% ~ 95%			Left ankle resting on right knee

Note. Hip position: The ratio of buttock-front tip length of seat to buttock popliteal length

Table 5.2 (Continued)

Selected posture	Included posture	Description	Posture discrimination criteria: Hip position	Upper body position	Leaning on the backrest?	Leg position
Sitting at the front edge		A person sits on the front of the seat without resting on the back of the chair.	~ 50%		No	
Slouching		A person sits on the front of the seat and leans their upper body backward against the backrest.	~ 50%	Extension: 10°~ (*Extension until fully leaning against the back plate with the defined hip position)	Yes	
Crossed-legs		A person bends both knees inward, placing each foot on the knee of the opposite leg.	80% ~ 95%			Both knees are bent and crossed inward positioning both feet on the opposite legs

Note. Hip position: The ratio of buttock-front tip length of seat to buttock popliteal length

5.2.3.3 Procedure

Each participant sat on the chair in front of the desk. The chair and desk were adjusted to fit their body based on anthropometric recommendations (Panagiotopoulou et al., 2004). Each participant was given a verbal description of postures with supplementary figures until they could understand and perform each posture correctly. Next, pressure data for each posture were collected for thirty to forty seconds. During this time, participants were allowed to move within the acceptable ranges in the definition of each posture (Table 5.2). Movement was facilitated to prevent repetitive measurements of the same data during the measurement period and acquire data for various sub-postures that can occur within the definition of each posture. The participants were carefully monitored in real time to verify that they moved within the definition of each posture. This was then checked again using the recorded video. The selected postures were given in counterbalanced order. The total time for data acquisition was approximately an hour for each participant, including time for setup, instruction, and breaks. All participants received monetary compensation for their efforts.

5.2.4 Classification Algorithm

A CNN was used to predict sitting postures. CNNs which was introduced by LeCun and Bengio (1995) have become widely used in various fields, such as speech and image recognition (Abdel-Hamid et al., 2014; Krizhevsky et al., 2012; Sainath et al., 2013), and have been proven to be reliable and powerful by many researches. A CNN is a type of multi-layer perceptron, but it is specialized for two-dimensional inputs by introducing convolution and sub-sampling techniques. Conventional neural networks cannot reflect characteristics of dimensionality because they consider inputs linearly. CNNs can also be optimized to handle computer vision tasks by introducing filters. A CNN consists of two types of layers called convolutional and pooling layers, which effectively reduce the number of weight parameters. Therefore, the complexity of a CNN is reduced by introducing these types of layers.

Because the acquired data (8×8) were too small to be optimal inputs for a CNN, it was necessary to adjust the inputs to a more appropriate size (16×16) through linear interpolation. This interpolation can represent inputs more densely and can smoothly represent the differences between pressure values (see Figure 5.4 (a) and (b)). After interpolation, the inputs were min-max normalized to make pressure the distributions for the same posture from different subjects more similar (see Figure 5.4 (b) and (c)).

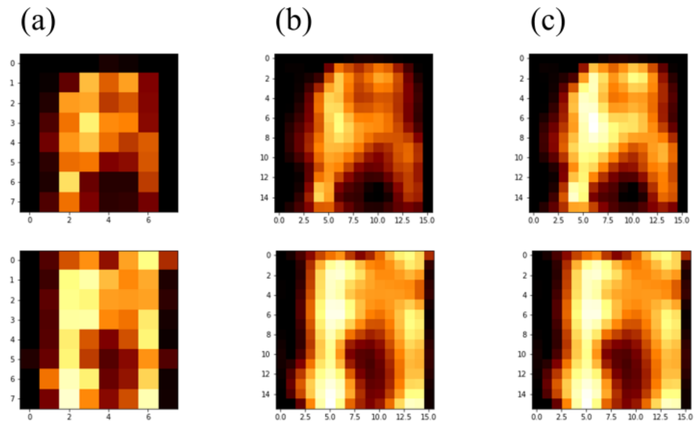


Figure 5.4 Transformation process for raw pressure distribution data. (a) Pressure distribution map from raw data, (b) Refined pressure distribution map from interpolation, (c) Refined pressure distribution map from normalization

In this sturdy, the applied CNN consisted of four convolution and sub-sampling layers. In each layer, 50 feature maps were generated and 2×2 filters were used between the convolution and sub-sampling layers. Following the two pairs of convolution and sub-sampling layers, a fully connected layer with 100 neurons was connected to the output layer. The full architecture is illustrated in Figure 5.5.

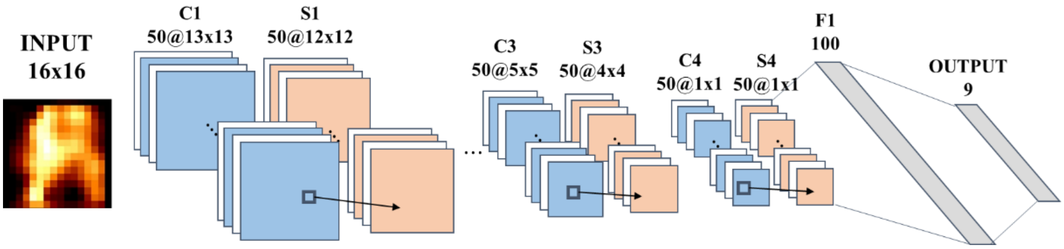


Figure 5.5 Structure of the CNN. C, S, and F denote convolution, sub-sampling, and fully connected layers, respectively.

5.3 Results

The collected data was used to train the CNN model to classify the nine postures. The performance of the model was evaluated considering three applicable usage scenarios. The first is usage by a familiar identifiable user. In this situation, the user's pressure distribution data for each posture is in the known dataset and the system classifies postures with the user's own data set. The second scenario is usage by a familiar unidentifiable user. In this situation, the user's pressure distribution data for each posture is in the known dataset and the system must classify the posture using the entire dataset because it does not recognize the user. The final scenario is usage by an unfamiliar user. In this situation, the system must classify the posture of the user using data from other users. The methodology and results of the experiments for each usage scenario are described in order in sections 5.3.1, 5.3.2, and 5.3.3.

5.3.1 Results of experiment 1

Experiment 1 was conducted using individual data. For each participant, 70% of their own data were randomly selected as a training set and the remaining 30% were used as a test set. Table 5.3 shows the results of predicting postures for each participant. The average training rate and accuracy were 99.88% (97.00 – 100.00) and 99.66% (95.00 – 100.00), respectively.

Table 5.3 Results of experiment 1

Participant ID	Training Rate [%]	Accuracy [%]
1	100.00	100.00
2	100.00	100.00
3	100.00	100.00
4	100.00	100.00
5	100.00	100.00
6	100.00	100.00
7	100.00	100.00
8	100.00	100.00
9	100.00	100.00
10	100.00	100.00
11	100.00	100.00
12	100.00	99.80
13	97.00	95.00
14	100.00	100.00
15	100.00	99.80
16	100.00	99.00
17	100.00	100.00
18	100.00	99.40
19	100.00	100.00
20	100.00	99.00
21	100.00	99.80
22	100.00	100.00
23	100.00	100.00
24	100.00	100.00
Avg.	99.88	99.66

5.3.2 Results of experiment 2

Experiment 2 was conducted using the entire dataset. For each user, 70% of the entire posture dataset was randomly chosen as a training set and the remaining 30% was used as a test set. The training rate and accuracy were 100.00% and 99.40%, respectively (Table 5.4).

Table 5.4 Results of experiment 2

	Training Rate [%]	Accuracy [%]
Total	100.00	99.40

5.3.3 Results of experiment 3

The leave-one-out method was used in experiment 3. This experiment was performed to predict postures for each participant using the data of the other 23 participants as the training set. Table 5.5 summarizes the training rates and accuracies when data from each participant were used as test data. The average training rate and accuracy were 99.79% (99.33 – 100.00) and 77.35% (61.00 – 93.20), respectively.

Table 5.5 Results of experiment 3

Participant ID	Training Rate [%]	Accuracy [%]
1	99.67	76.40
2	99.67	73.00
3	100.00	80.20
4	99.67	84.20
5	100.00	77.00
6	99.67	81.60
7	99.67	71.00
8	100.00	92.20
9	99.67	73.00
10	100.00	70.80
11	99.67	69.00
12	99.67	91.80
13	99.67	72.20
14	100.00	93.20
15	100.00	61.00
16	100.00	65.40
17	99.67	80.40
18	100.00	77.40
19	100.00	64.40
20	100.00	65.40
21	99.67	88.60
22	99.67	82.60
23	99.33	80.00
24	99.67	85.60
Avg.	99.79	77.35

5.4 Discussion

5.4.1 Overall results

The accuracies of classification in experiments 1 and 2 were very good, but the accuracy in experiment 3 was relatively low (Figure 5.6). The same result was obtained in a previous study (Tan et al., 2001). This result suggests that if a user's posture data is included in the training data, it has a significant effect on classification performance. This is because pressure distributions differ according to the physical characteristics of users, even for the same posture (Moes, 2007).

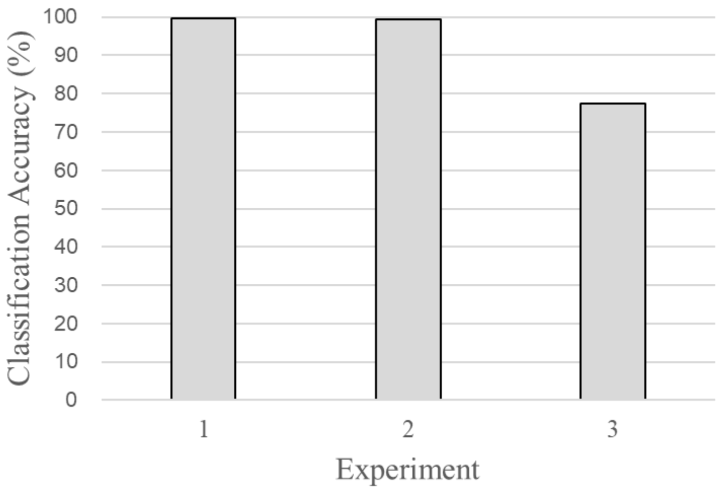


Figure 5.6 Summary of experimental results

The average accuracy of classification in experiment 1 was 99.66%. This result is superior when compared to the results of a previous study (95% in a study of Tan et al. (2001)). Although Tan et al. (2001) predicted more postures, they also equipped expensive commercial pressure sensor mats on both the backrest and seat pan of a chair. Therefore, it can be concluded that the hardware and classification method used in this study are very effective and efficient at predicting sitting postures.

The average accuracy of classification in experiment 2 was 99.4%. This result is superior to the results of similar experiments in previous studies (96% in a study of Tan et al. (2001); 85.9% in a study of Xu et al. (2013); 94.2% in a study of Bao et al. (2013)). Considering the fact that previous studies classified fewer postures (five postures in a study of Bao et al. (2013); seven postures in a study of Xu et al. (2013)) or used a larger number of sensors (8,064 sensors in a study of Tan et al. (2001); 256 sensors in study of Xu et al. (2013)), the performance of the sensor and CNN could be interpreted as being superior to previously applied.

The average accuracy of classification in experiment 3 was 77.35%. This is slightly lower than the experimental results from leave-one-out method tests in previous studies (79% in a study of Tan et al. (2001); 81% in a study of Meyer et al. (2010); 90.9% in a study of Zemp et al. (2016a); 82.7% in a study of Zemp et al. (2016b)). This result can be attributed to the fact that relatively few sensors were used and that sensors were attached to only the seat pan of a chair in this study. This argument is supported by the results of a previous study (Meyer et al., 2010). Meyer et al. (2010) compared the performance of two static sitting posture classification systems. One used only pressure data from the seat pan and the other used both pressure data from seat pan and backrest. The results demonstrated that if pressure data from the backrest was not used, the accuracy of classification fell dramatically from 81% to 55%. Zemp et al. (2016a) used a smaller number of pressure sensors to predict posture, but attached pressure sensors to the backrest and armrest in addition to the seat pan. Additionally, a motion module was attached to their chair to utilize the backrest angle as an input variable. Zemp et al. (2016b) only used 64 pressure sensors attached to the seat pan, but also classified fewer postures (seven postures).

5.4.2 Recall value for each posture

The accuracies in experiments 1 and 2 were close to 100%. However, the accuracy in experiment 3 was significantly lower, so it is necessary to discuss the recall values (same as recognition rate) for each posture in this experiment. The recall value for each posture is presented in Figure 5.7. While the recall values for the leaning left and right postures were high, the recall values for the upright, leaning forward, and crossed-legs postures were low. As shown in Figure 5.8, the postures with high recall values had distinct pressure distributions and the postures with low recall values did not. There were many cases where the upright posture was misclassified as the leaning forward posture, leaning forward posture was misclassified as the upright posture, and crossed-legs posture was misclassified as the leaning forward posture (Table 5.6). As shown in Figure 5.8, the pressure distributions of the upright posture and leaning forward posture are similar. The fact that that these two postures share many common features has already been demonstrated in a previous study (Xu et al., 2013). However, the similarity in pressure distributions between the crossed-legs posture and leaning forward posture was an unexpected result because these two postures are clearly very different. This result is noteworthy because the crossed-legs posture is a very common posture in Asia. Further study is needed to distinguish between these two independent postures accurately.

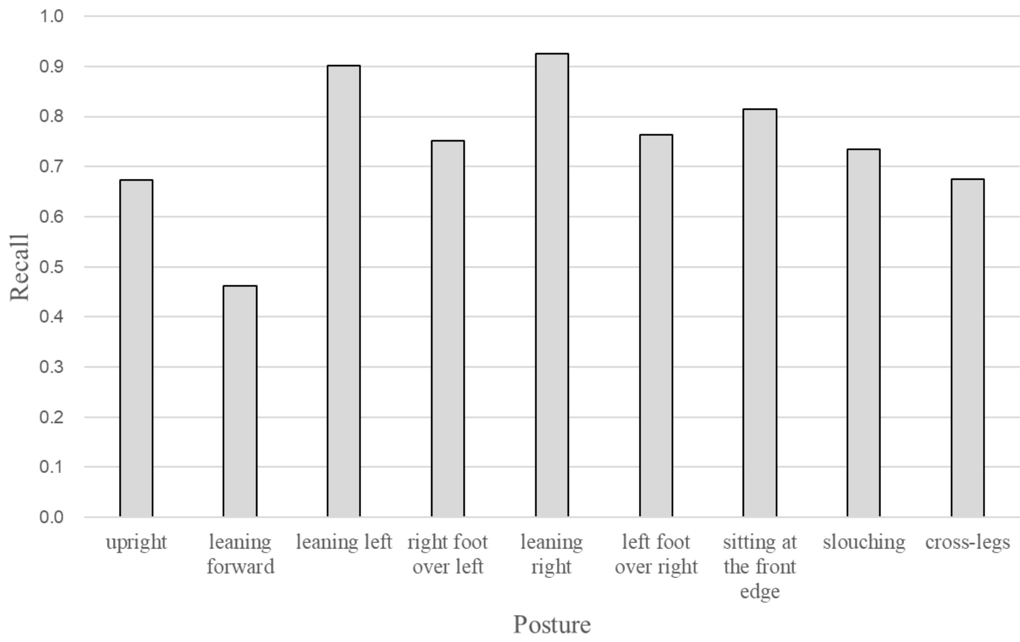


Figure 5.7 Recall value for each posture

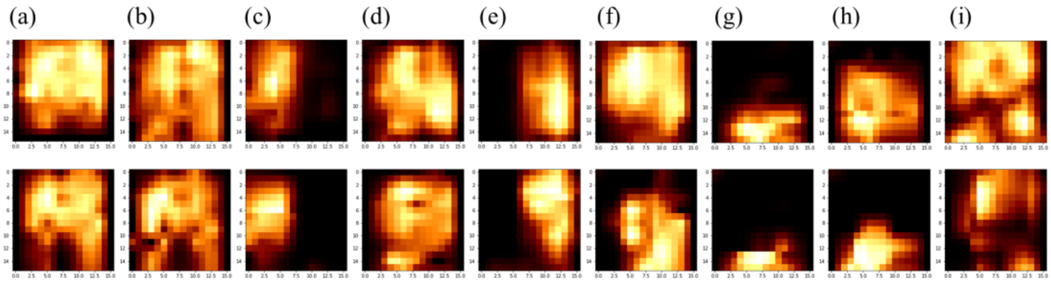


Figure 5.8 Example pressure distribution maps of nine postures from different participants (Top: Participant 23, Bottom: Participant 18). (a) good posture, (b) leaning forward posture, (c) leaning left posture, (d) right foot over left posture, (e) leaning right posture, (f) left foot over right posture, (g) sitting at the front edge posture, (h) slouching posture, (i) crossed-legs posture.

Table 5.6 The confusion matrix for experiment 3

		Assigned sitting postures									
		Good	Leaning forward	Leaning left	Right foot over left	Leaning right	Left foot over right	Sitting at the front edge	Slouching	Cross-legs	Recall value
True sitting postures	Good	1006	284	41	17	18	67	4	0	58	0.673
	Leaning forward	442	679	56	50	32	69	36	12	91	0.463
	Leaning left	119	21	2288	12	9	3	14	35	34	0.903
	Right foot over left	31	48	62	614	5	8	1	23	24	0.752
	Leaning right	46	25	3	9	2309	25	32	23	21	0.926
	Left foot over right	23	60	11	2	34	629	0	14	51	0.763
	Sitting at the front edge	0	1	19	0	52	0	657	76	2	0.814
	Slouching	6	29	25	7	16	54	66	560	0	0.734
	Cross-legs	27	166	16	28	19	3	0	1	540	0.675

5.4.3 Further application as a discriminator of good posture

It is important to predict exactly what type of posture users assumed, but it is also important to discriminate between whether or not users assumed good posture for posture correction. In this section, the performance of the proposed system when it is used as a good posture discriminator is evaluated. Evaluation was performed with a focus on cases when the system is applied to unfamiliar users for reasons described in Section 5.4.2. Table 5.7 is the combined confusion matrix of Table 5.6 for two postures: good posture and poor posture (all postures other than good posture). The recall value for good posture was 0.67 and the recall value for poor posture was 0.93. It should be noted that positive predictive value (PPV) and negative predictive value (NPV) are more important than the other performance metrics when considering application of the system in the real world. In this situation, PPV is the probability that a user's actual posture was good when the system predicted that the posture was good and NPV is the probability that the user's actual posture was bad when system predicted that the posture was bad. The reason why PPV and NPV are particularly important in a posture discrimination system is that the actual posture of a user is unknown in a real usage situation and only the prediction result from the system can be used as a cue for the true posture of the user. The PPV and NPV of the suggested good posture discriminator system were 0.59 and 0.95, respectively. However, the training data used in this study does not represent the actual sitting posture behavior of the entire child population because the number of collected data for each posture was controlled. Because PPV and NPV depend on the prevalence of good posture, these values may vary between users because sitting posture behavior is different for each user. In the absence of additional training data, it can be assumed that calculated recall values of good and bad posture are applied to all users equally. Under this assumption, the change patterns in PPV and NPV with the prevalence of good posture are presented in Figure 5.9. As shown in the figure, the discriminant performance of the system changes according to the prevalence of good posture. Both PPV and NPV are greater than 0.7 when the prevalence of good posture is between 0.21 and 0.55. False discovery rate (FDR), with is the complement of PPV, is critical for the purposes of the system. If bad postures are misjudged as good postures, the opportunity for posture correction may disappear. If the system was applied to users with very poor postural habits, then FDR would be high. This means that the effectiveness of the system may be low initially because it views bad posture as good posture. However, it can be expected that FDR will decrease rapidly as the prevalence of good posture increases as users correct their improper sitting behavior through use of the system. In contrast, when a user with very good postural habits uses the system, the system may underestimate how often the user assumes good posture because false omission rate, which is the complement of NPV, would be high. If we improve the recall value for each posture through acquisition of additional training data and improvement of the classification algorithm, the performance of the good posture discriminator system would be better and more stable, irrespective of users.

Table 5.7 Combined confusion matrix

		Assigned sitting postures		Recall value
		Good	Poor	
True sitting postures	Good	1006	489	0.673
	Bad	694	9811	0.934

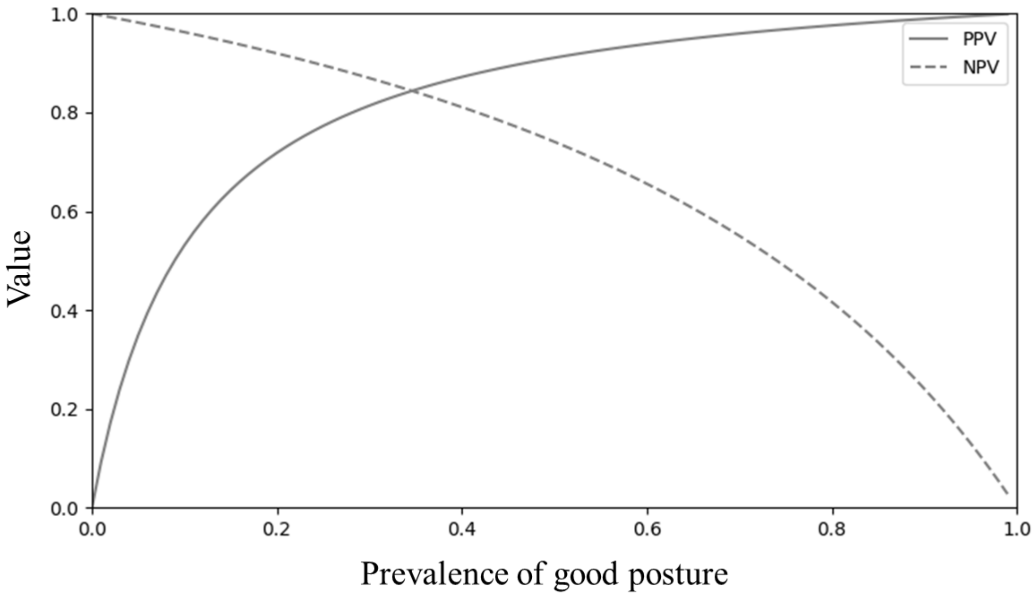


Figure 5.9 Prevalence of good posture vs. system prediction performance (PPV & NPV)

5.5 Conclusion

Sedentary behavior is common in daily life and the formation of proper sitting postural habits during childhood is important for preventing musculoskeletal disorders that may lead to back pain and hinder physical development. Improper postural habits during childhood are likely to remain in adulthood and cannot be easily corrected by oneself. For these reasons, we collected the pressure distribution data of nine postures from children using self-developed film-type pressure sensor, and classified sitting postures using CNN. The sitting postures selected for prediction were defined qualitatively and quantitatively to provide more information to users during practical use of the system. Furthermore, considering economic efficiency and practical application suitability, sitting posture data obtained noninvasively in real time by using a custom-made film-type pressure sensor. When measuring the data for each posture, more data from each posture was collected by providing degrees of freedom for the upper body. This precaution guarantees greater versatility in actual use. A CNN algorithm was applied to predict sitting postures and its performance was excellent in three different experiments compared to previous studies, considering the number of pressure sensors and wide range of each posture. However, there are still some postures which are not included in our study. For the results of this study to be more useful in real-world, more postures need to be predicted. In the future, we will collect the data of additional postures and improve the classification algorithm for the development of robust and accurate posture monitoring system. Furthermore, we will study effective methods, which will help children to be aware of their sitting posture and correct improper posture in real-time. In spite of some limitations, it is expected that the applied techniques and the results of this study could contribute the development of posture monitoring and correcting systems which can be used in personal sitting environments or public institutions, such as schools.

Chapter 6

Conclusion and Discussion

6.1 Summary of findings

This study aimed to solve the problem of poor posture during sedentary work, particularly in children.

Chapter 3 confirmed that the height system of preliminary school furniture was not well matched to the anthropometric characteristics of Korean children. Based on the anthropometric mismatch equations suggested in previous studies, a mismatch analysis was conducted that revealed that the currently used desk consisting of seven height levels could be matched to only half of the children. The major cause of the mismatch problem was the desk drawer attached underneath the desk surface; thus, its removal could effectively solve the mismatch problem. However, it is difficult to say that this solution is a realistic course of action. On the other hand, the results showed that the currently used chair (also with seven height levels) could be matched to almost children, but some of the levels were useless. To solve the mismatch problem, a new height system for desks and chairs were developed using the algorithmic approach. The optimal set of desk and chair height levels could be driven based on the idea that maximizing the number of matchable children using the target number of height levels could be a maximum coverage problem. Finally, the new height systems are significantly better. The new desk height system consisting of seven levels could be matched to 79.80% of the children, while the new chair height system consisting of five levels could be matched to 100.00% of children. Moreover, to match more than 90% of children, 15 and three height levels are needed for the desk and chair, respectively.

In Chapter 4, it was tested how much the currently used guideline can help children use the anthropometrically appropriate height level of school furniture and how able the children are to select the appropriate height levels. It was shown that 76.62% and 74.38% of children who have at least one recommendable height level among the seven levels could be allocated to anthropometrically recommendable height level according to the currently used guideline. It was also found that 71.43% and 76.19% of children did not choose the recommended desk and chair height, respectively, when they were instructed to adjust the desk and seat height to the recommendable heights. In particular, the majority of children selected too high a desk height and seat height. It could be inferred that the currently used guideline is not well suited for children and they have been familiarized to sitting furniture for adults. Finally, new simple guidelines were developed using machine learning techniques, and it was confirmed that most of the children (greater than 90%) could be allocated to their recommendable desk and chair height levels according to the new guidelines.

In Chapter 5, a sitting posture monitoring system was developed using pressure sensors. To develop the system, 64 force sensitive resistor sensors were inserted into the seat cushion and the pressure distribution data of nine predefined postures were acquired from 24 children. The CNN was selected as a classification algorithm, and three classification experiments were conducted of the system for three different usage scenarios. The first experiment was conducted under the assumption that the system can identify the sitter; the sitter's posture data are stored in the system. The experiment showed that the system can very accurately recognize the sitter's posture (99.60%). The second experiment was conducted under the assumption that the system cannot identify the sitter, but the sitter's posture data have been stored in the system. The experimental results showed that the system can recognize the sitter's posture very accurately (99.40%). Finally, the third experiment was conducted considering the new user. In this experiment, the classification accuracy was 77.35%. In particular, the upright, leaning forward, and crossed-leg postures had relatively lower recall values than other postures because of their similar pressure distributions. In addition, system performance was evaluated for discriminating good and poor posture. The results showed that the performance could vary according to the sitter's postural behavior and would increase as the sitter's postural habits are corrected.

6.2 Suggested integrated approach to managing working posture during sitting work

The thesis aimed to manage the problem sources identified in pediatric population. In this section, the research methods in Chapters 3, 4, and 5 were summarized and generalized for solving the problems possibly arisen in diverse sedentary works and populations. Figure 6.1 outlines the proposed integrated confrontation strategies to manage a sedentary working posture. First, to solve the problem caused by the use of an improperly designed workstation, a process to evaluate and improve its design was suggested. Second, a procedure to develop a simple guideline for size selection was proposed. to manage the problem caused by the mis-selection of workstation size. Finally, to manage the problem caused by a poorly formed postural habit, a process of developing a posture monitoring system was suggested.

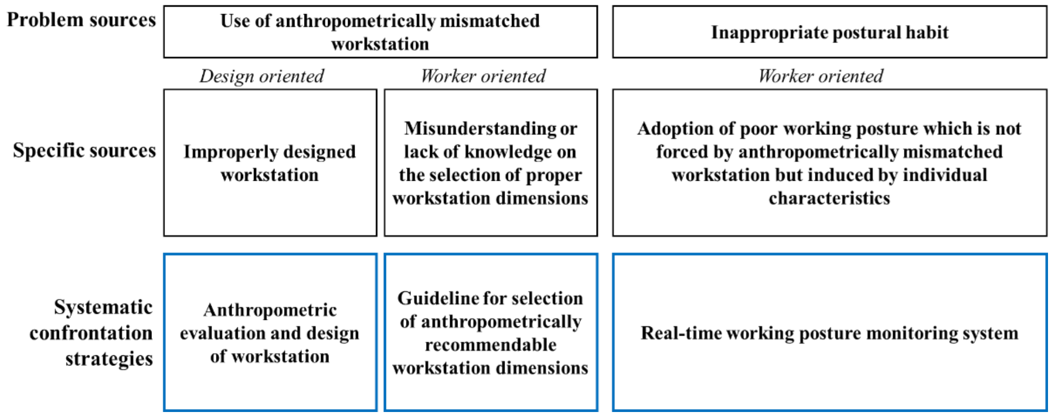


Figure 6.1 Outline of integrated confrontation strategies to manage sedentary working posture problem

6.2.1 Anthropometric workstation evaluation and design

In Chapter 3, the anthropometric evaluation and design improvement of the height system of primary school furniture were conducted. In this study, the seat and desk heights were selected as critical dimensions affecting sitting position based on the literature review. To evaluate the anthropometrical suitability of height systems of school furniture, the anthropometric data from children were acquired and the mismatch equations were justified. As a result, the height systems had serious problems in terms of the anthropometric design concept, so they were improved using the algorithmic approach.

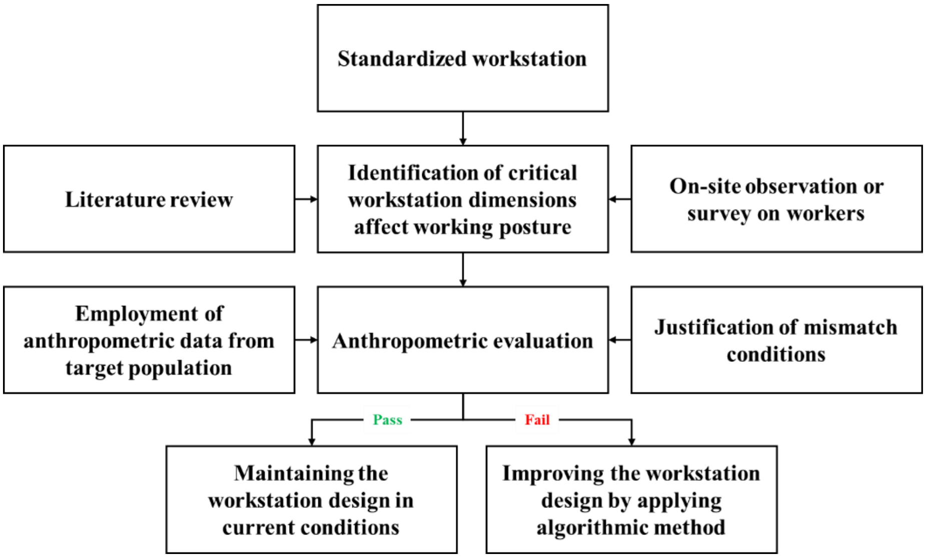


Figure 6.2 Process to anthropometrically evaluate and improve workstation design

Figure 6.2 shows a flow chart of the method used to evaluate and improve the standardized workstation design. In the first step, workstation dimensions should be identified that affect the working posture critically based on the literature review and on-site observation or survey on workers. As the author reviewed in Chapter 2, various dimensions could influence on the working posture such as height, seat depth, seat width, backrest height, desk height, and desk clearance. On the other hand, working tools must be considered carefully because the working posture could vary according to tool dimensions of tools even if the same worker performs the same task. For instance, the keyboard and mouse require consideration in a VDT task, while a screwdriver should be considered in an assembling task. For the next step, anthropometric mismatch conditions for selected dimensions should be justified. In other words, anthropometrically acceptable limits of each dimension should be defined according to related anthropometric dimensions. For example, the lower and upper limits of seat height were expressed by popliteal height, while the upper limits of desk height were expressed by popliteal, elbow, and shoulder heights in Chapter 3. The justification could be made by experimental research or a literature review. After justifying the mismatch conditions of selected critical dimensions, the data of anthropometric measures included in the mismatch conditions should be acquired from the target population. For example, four anthropometric measures (popliteal height, elbow height, shoulder height, and knee height) were related to mismatch conditions of seat, desk, and underneath desk heights, so the data were acquired from primary school children. It could be confirmed for each person whether the currently used workstation was appropriate. As a result, the anthropometric evaluation of standardized workstation could be conducted using anthropometric data and mismatch conditions. In other words, it could be determined whether the currently used workstation was matchable to the target user ratio. If the analysis results indicate that currently used workstation has serious problems, it could be improved by the proposed algorithmic solution. The algorithmic solution was proposed based on the concept in which the problem of maximizing the number of matchable people using a finite number of size system levels can be treated as a maximum coverage problem. Here the proposed algorithmic method to solve this problem is based on the greedy algorithm for the maximum coverage problem.

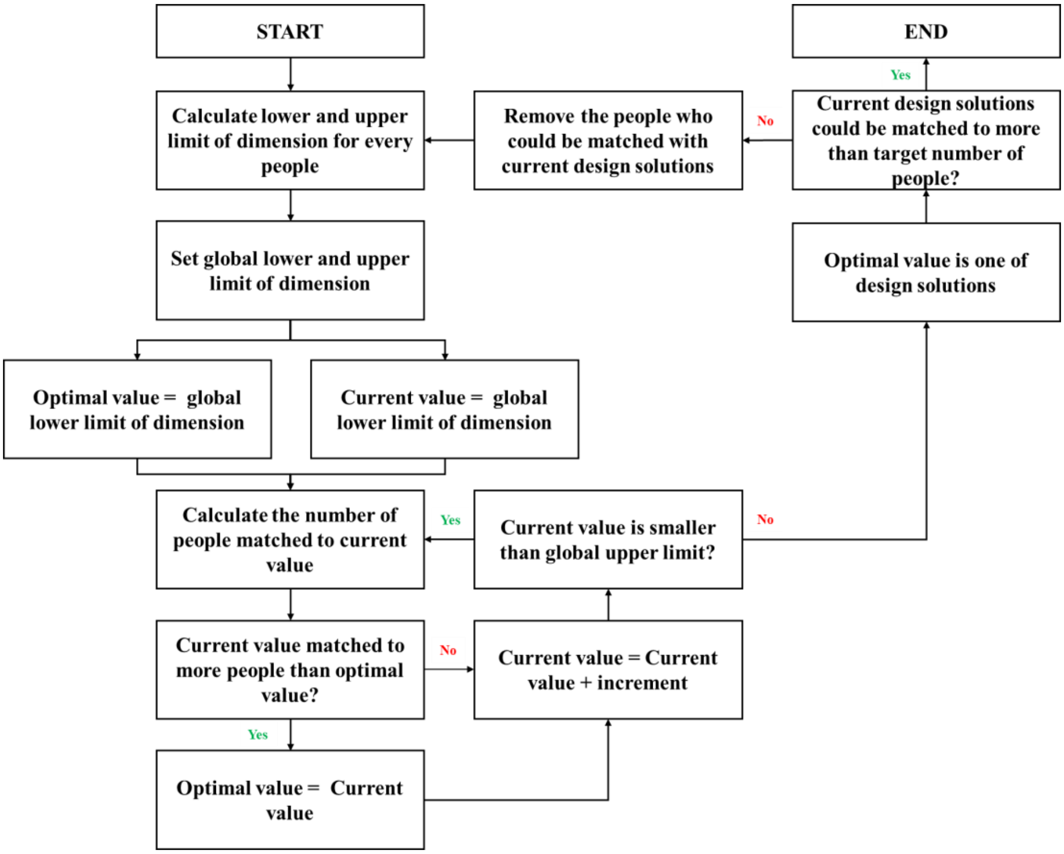


Figure 6.3 Proposed algorithmic approach to deriving an anthropometrically optimal set of workstation size

Figure 6.3 shows the structure of the proposed algorithmic approach. First, determine the lower and upper acceptable limits of the selected dimensions for every person using employed anthropometric data and justified mismatch conditions of the dimensions. Second, one must determine the global acceptable limits of dimension in the population. Third, set both the optimal value and the current dimensions as the global lower limit. At that time, the number of people matched to the optimal value is the maximum number of matchable people. Fourth, calculate the number of people matched to the current value. Fifth, determine whether the current value could be matched to more people than the optimal value or vice versa. If the current value is better than the optimal value, change the optimal value to the current value. Sixth, increase the current value and iterate the fourth to fifth step until the current value is smaller than the global upper limit. One size level in the optimal set of dimensions could be derived at the end of the iteration. Seventh, remove the people who could be matched to a derived size if the set could not be matched to more than target ratio of population and iterate the first to sixth step.

This algorithm has some limitations. First, it could be applied to a large amount of anthropometric data from a target population. If this algorithm is applied to the data from a relatively small number of people, a driven solution could be quite different from the optimal size system in the entire population. Second, the proposed method can be used to derive an approximate optimal solution. Beyond these limitations, this method is still meaningful for anthropometric design. First, the necessary number of levels to accommodate a target ratio of a population can be easily calculated. This is very useful in product planning. Second, this method could be utilized without problems even if the critical dimensions are large or their mismatch conditions are complex. One well-known method proposed by Molenbroek et al. (2003) for the design of sitting furniture has problems when both lower and upper acceptable limits are defined in a mismatch condition.

6.2.2 Development of the guideline for workstation size selection

In Chapter 4, the author evaluated the guideline as well as the children's ability to select anthropometrically recommendable sitting furniture height. First, to evaluate the guideline, the mismatch analysis was conducted using anthropometric data from children and the mismatch equations for the seat, desk, and underneath desk heights from the literature review results. As a result, the currently used guideline was not appropriate for the present generation of Korean children. Second, to evaluate the children's ability to adjust the height of sitting furniture to anthropometrically recommendable height, a self-adjustment experiment and mismatch analysis were conducted. The analysis revealed that children were likely to set the height of sitting furniture significantly higher than their anthropometrically acceptable upper limit. Finally, a new guideline was developed using machine learning algorithms.

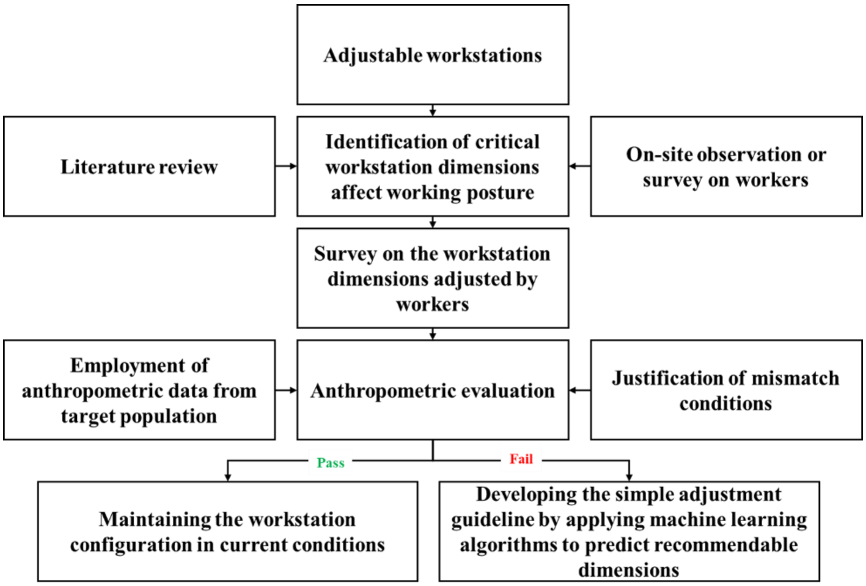


Figure 6.4 Process used to evaluate the guideline and worker ability to select the anthropometrically recommendable size

Figure 6.4 shows the process used to manage the problem caused by a faulty guideline and lack of knowledge of proper adjustment. First, as with the anthropometric evaluation of workstation design, the identification of critical workstation dimensions should be identified. Second, a worker's ability to select anthropometrically recommendable dimensions must be checked. This could be achieved in the self-adjustment experiment. In this experiment, a significant number of participants will be recruited from the target population and their anthropometric dimensions carefully measured. Thereafter, an anthropometric evaluation could be conducted using their anthropometric characteristics, self-chosen workstation dimensions, and justified mismatch conditions. If the evaluation results report an insufficient ability to select proper dimensions, a guideline to assist with the process should be developed and trained. If the guideline already exists, its suitability should be tested. An anthropometric evaluation of the guideline could be conducted easily as follows. First, allocate everyone in question to a single size that is recommended by the guideline. Second, calculate the ratio of people who could be anthropometrically matched to the allocated size. Third, determine whether the ratio of people exceeds the target ratio. If the results of the evaluation concluded that the currently used guideline has no problem, no improvement is needed. If the opposite is found, however, a new guideline should be developed.

The size recommendation system could be developed using machine learning algorithms. Figure 6.5 illustrates the development procedure. First, calculate the lower and upper acceptable limits of dimensions using a justified mismatch condition of workstation dimension for each individual from whom acquired anthropometric data were derived. Second, calculate the median value of the recommendable range. Third, allocate people to one size level that has a minimum difference with median value. Fourth, select input variables among anthropometric measures. In this step, two standards should be considered to ensure guideline ease of use. The anthropometric measures that are easily measurable and representative should be chosen as input variables. Demographic information such as age and sex could be considered input variables. Fifth, select the classification algorithm. One thing to note is that the algorithm should derive the classification rules. For instance, in

Chapter 4, a multinomial logistic regression and decision tree were utilized. To increase the guideline's effectiveness and ease of use, the classification accuracy should be maximized using a minimal number of input variables. And finally, the guideline must be developed based on the derived classification rules. At this time, it could be more effective if the rule is presented graphically.

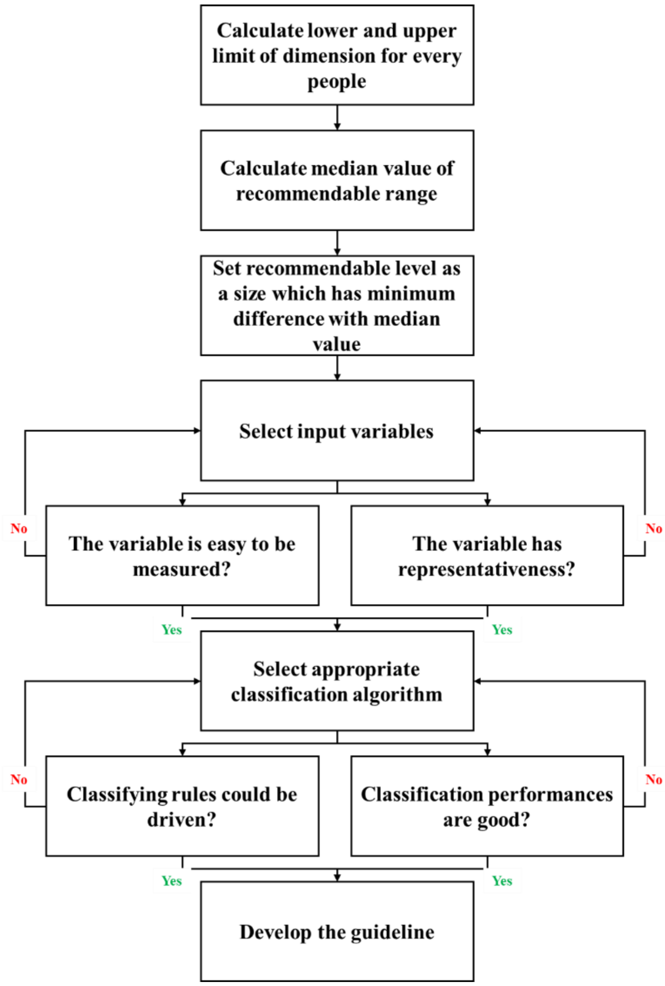


Figure 6.5 Process used to develop a guideline for selecting an anthropometrically recommendable chair and desk size

6.2.3 Development of sitting posture monitoring system

In Chapter 5, the author developed the sitting posture monitoring system using pressure sensors. In this study, 15 postures which are most frequently taken during the sitting work were selected and operationally and biomechanically defined in the literature review. On the other hand, a sensor array was configured using a force resistance sensor and inserted into the seat cushion to non-invasively acquire the pressure distribution data. After then, pressure distribution data of each posture was acquired from children and the classification experiments were conducted using the CNN. The experimental results confirmed that the system could perform well in various usage scenarios. This system could be utilized directly as a real-time posture correction system.

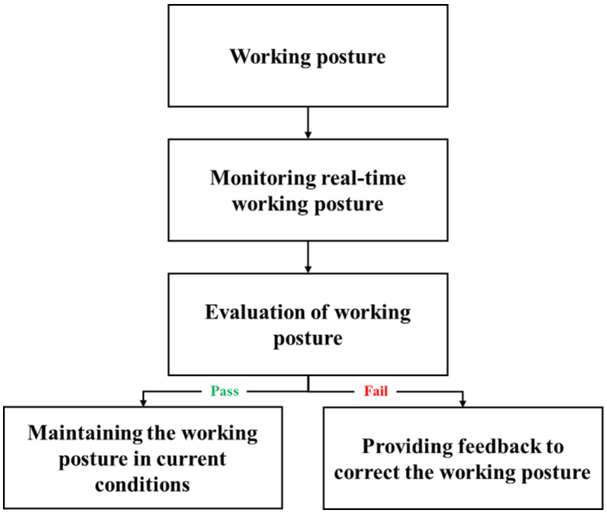


Figure 6.6 Concept of correcting working posture using a real-time posture monitoring system

Figure 6.6 shows the simple concept of posture correction strategy using a real-time posture monitoring system. The system monitors the worker's posture during work and provides feedback when the adoption of an awkward posture is detected. This concept has been suggested by many researchers, who contended that the posture correction method based on this concept would be more effective than the currently used method. This concept is quite simple, but the development of the posture monitoring system is quite challenging.

Figure 6.7 Process used to develop real-time posture monitoring system for correcting working posture

Here the author summarized the process used to develop the sitting posture monitoring system based on the insights from the study described in Chapter 5. Figure 6.7 illustrates the process used to develop the real-time sitting posture monitoring system.

First, justify the target population by considering the workers' characteristics. This is very important because anthropometric characteristics could continue to vary according to the population. The anthropometric characteristics may significantly affect the measured value from sensors even in the same posture.

Second, justify the representative working postures, including both recommendable and harmful postures. When selecting the postures, the characteristics of the postures such as adoption frequency and the biomechanical and cardiovascular risk should be carefully considered. These characteristics of various postures could be identified through a literature review and on-site worker observation or survey. After selecting the postures, they must be defined specifically. This is very important in the data acquisition step. Moreover, the system could be unreliable without a detailed definition of the predicted postures.

Third, develop the hardware configuration. At this step, the configuration should satisfy both non-invasiveness and precision criteria. Non-invasiveness of the sensors is very important because an invasive sensor could distract the natural movements of the worker and eventually impede their performance. Generally, however, there is a trade-off between sensor non-invasiveness and precision. Thus, sensor type should be selected carefully. One of the best solutions is the use of pressure sensors. The pressure sensors do not obstruct the natural movement of the seated individual but have also been proven useful for recognizing posture. The use of depth or inertial sensors may help increase the classification accuracy when the chair has a backrest or the seat is rotatable, respectively.

Fourth, conduct an experiment to construct a database that contains sensing data of defined working postures. When designing an experiment, the data must be collected effectively and efficiently. First, the participants should be recruited from the target population. As the author mentioned before, the anthropometric characteristics of the participant may significantly affect the sensing data. Understandably, the more participants the better. However, the number of participants cannot help but be limited due to time and economic costs. Therefore, a stratified sampling should be done. One of the most important eligibility criteria requiring consideration involves the anthropometric characteristics such as weight and stature. Second, as much sensing data of each posture should be gathered as possible. This is necessary to apply deep learning methods. To acquire a large amount of data effectively and efficiently, the data should be acquired continuously by sensors at a high sampling rate. Gathering the data in this way with excessively repetitions of exactly the same posture should be avoided. If the amount of data from same posture increases, the classification performance could be better. However, the practicality and effectivity could be deterred considering that the various posture could be adopted in real-world situation. Therefore, the data of each posture should be recorded while the participant continuously moved unless the momentarily adopted posture does not correspond to the definition of posture.

Fifth, pre-process the raw sensing data and extract the input features. This is not a mandatory step, but the classification accuracy could be increased through this step. One typical pre-processing method is normalization, which can reduce the differences in data from different participants. Various features have been extracted and utilized as input variables in previous studies related to the development of sitting posture monitoring system using pressure sensors. For example, Zhu et al. (2003) utilized contact area, Meyer et al. (2010) used x and y coordinates of the center of pressure, and Zemp et al. (2016b) employed body weight as input variables.

Sixth, select the classification algorithm. Previously, various algorithms such as artificial neural network (Ma et al., 2016; Martins et al., 2014; Mota and Picard, 2003; Pereira et al., 2015; Ribeiro et al., 2015; Zemp et al., 2016b), support vector machine (Kazuhiro et al., 2008; Ma et al., 2016; Zemp et al., 2016b), decision tree (Ma et al., 2016; Zemp et al., 2016b), random forest (Zemp et al., 2016a; Zemp et al., 2016b), logistic regression (Mutlu et al., 2007; Zemp et al., 2016b), Naïve Bayes classifier (Meyer et al., 2010) were used to develop a pressure sensor–based sitting posture monitoring system. It is difficult to state which of the classifiers is best for the development of a sitting posture monitoring system because classification performance could vary according to the characteristics of the data set and input variables. In Chapter 5, it was shown that a CNN could be a good choice. This algorithm was chosen based on the idea that the pressure distribution map could be treated as a kind of image and it was proven that the algorithm performs well without any special input features.

Seventh, train the data and test the system. Before that, the usage scenario of the system should be decided. Three usage scenarios could exist: usage of familiar and identifiable users, usage of familiar and unidentifiable users, and usage of unfamiliar users. The usage of a familiar user means that the user has experience using the system so the system has the pressure distribution data of the user's postures. The use of an identifiable user means that the system could recognize them. Training and testing of the algorithm should be conducted differently according to system type. To develop the monitoring system for familiar and identifiable users, the algorithm should be trained and tested using data from each user by the hold-out method. In other words, the algorithm is developed individually so the system predicts a user's posture using the data set from that user. To develop a system for familiar but unidentifiable users, the algorithm could be trained and tested by the k-fold cross-validation method. In particular, an algorithm could be developed based on the data from multiple users, so the system predicts a user's posture using whole data set. To develop a system for unfamiliar users, the algorithm should be developed and tested using the leave-one-out method. Specifically, the system could predict the user's posture based on the data set from other users.

In this section, an integrated approach was proposed to handle the poor working posture problem caused by the anthropometrically mismatched workstation and the poor postural habit based on the empirical knowledge acquired from Chapters 3, 4, and 5. It was derived inductively from the studies focused on the children's problem but it is expected that the proposed approach help researchers who try to improve worker's sitting posture in other various seated works.

6.3 Contributions of this study

The findings from this study are expected to help children adopt a safe posture while sitting. This study revealed a serious problem in school furniture design and their usage guidelines. The suggested new height systems of school furniture were proven to be more anthropometrically fitted to Korean children than the currently used systems. In addition, the newly developed guideline could increase the ratio of children who could be allocated to a recommendable height level. Finally, a sitting posture monitoring system was developed for real-time posture correction, so it is expected that children can form a good postural habit through this system. This study focused on children, but the author believes that the research process also could be adopted to solve poor sitting posture problems in diverse populations.

The contribution of this study could involve its findings as well as methods to acquire findings. First, the algorithmic approach that aimed to develop a new height system of school furniture could also be utilized to develop size systems for various products. Most ready-made goods have size systems for managing the anthropometric variety among consumer groups. When the mismatch equations of interested dimensions could be defined and the anthropometric data from the target population could be acquired, the proposed approach could be utilized to find the approximately optimal size system. Second, the machine learning–based method to develop a new guideline for selecting school furniture heights could provide insight into the development of a size recommendation system. Considering that the proposed algorithmic approach provided only an optimal set of size levels, a size recommendation system based on a machine learning technique could help consumers choose and use products with correct sizes. And finally, this study confirmed that postural characteristics are included in the pressure distribution map and that CNN performs well for classifying the pressure distribution map. Thus, it is expected that the hardware configuration and algorithms could be used to develop novel systems such as an abnormal state detection system or posture-based control system.

6.4 Limitations and further studies

This study aimed to examine and correct children's poor working posture problems caused by the use of anthropometrically mismatched sitting furniture and inappropriate postural habits. Although this study confirmed that the defined problem sources could be unraveled successfully, some limitations exist.

First, some constraints and limitations exist in the proposed method included in this integrated approach. In the case of the algorithm used to develop the size system, a relatively large amount of anthropometric data is needed to derive reliable results. In addition, the algorithm is based on the greedy algorithm for maximum coverage problem so there is the potential to improve the algorithm. In case of the posture monitoring system, pressure distribution data should be acquired from more children to ensure system robustness.

Second, the proposed integrated approach to improve working posture requires refinement and incarnation through case studies. It was developed based on the author's knowledge and experience from the studies in Chapters 3, 4, and 5. If more case studies focused on other works or populations are conducted, there may be opportunities for the proposed research process to be expanded to ensure robustness and concreteness.

Third, the effect of the proposed integrated approach should be verified. This study defined the problem sources based on the literature review and suggested a solution. The solutions are expected to make workers adopt safer and better sitting postures, but a verification experiment should be conducted to confirm their effects.

Finally, other factors causing the problem were not addressed in this study. For instance, as mentioned in Chapter 2, the working posture could be affected by the task characteristics. The working posture could be varied according to visual demand, force demand, and types of hand tools, even if a worker uses the same workstation. The task characteristics were beyond the scope of this study, but they require future consideration to more effectively improve working posture.

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국문 초록

오늘날 착석 작업은 매우 보편화 되었다. 착석 작업을 수행함에 있어 바른 자세를 유지하는 것은 매우 중요한데, 이는 장시간 부적절한 자세로 작업을 수행할 경우 근골격계 질환이 발병하거나 과업 수행 능률이 저하될 수 있기 때문이다. 특히, 아동의 경우, 바른 작업 자세의 중요성이 더욱 강조된다. 왜냐하면, 아동기에 발병한 근골격계 질환은 신체 발달에 부정적인 영향을 미치며, 아동기에 형성된 자세 습관은 쉽게 교정되지 않기 때문이다.

지난 많은 연구들에서 부적절한 작업 자세를 유발하는 다양한 요인들이 규명되어 왔다. 이러한 요인들 중 작업자에게 인체측정학적으로 부적합한 디자인의 작업 공간은 부적절한 작업 자세를 유발하는 주요한 요인으로 알려져 있다. 이에 따라 인간 공학 분야에서 아동들이 사용하는 작업 공간의 설계는 매우 중요한 문제로 다루어져 왔다. 이러한 맥락에서, 학교에서 사용되는 교구의 치수는 매우 신중히 결정되어야 하는데, 이는 학교가 대다수의 아동들이 많은 시간 동안 앉아서 학습하고 생활하는 곳이기 때문이다. 현재 한국 초등학교에서 사용되는 책상과 의자는 일곱 단계의 높이로 조절이 가능하며, 각 단계의 높이는 한국기술표준원에서 제공하는 표준인 “KSG 2010: 학생용 책상 및 의자”를 따르고 있다. 그런데, 본 표준은 수립 된지 너무 오래되었기 때문에, 이에 따라 제작된 책상 및 의자가 현 세대의 한국 아동들에게 인체측정학적으로 적합한지

의문스러운 실정이다. 설령 현재 책상 및 의자의 높이 시스템이 한국 아동들에게 여전히 적합하다 하더라도, 아동들이 자신에게 적합한 높이를 선택하여 사용할 수 있는가에 대한 문제가 제기될 수 있다.

한편, 작업자가 인체측정학적 특성에 적합하게 디자인된 작업 공간에서 작업을 수행한다 하더라도 작업자의 자세 습관이 좋지 않을 경우 부적절한 작업 자세를 빈번히 취할 수 있다. 따라서, 바른 작업 자세를 유지하기 위해서는 작업 자세 교육 및 교정을 통한 바른 자세 습관의 형성이 필수적이다. 그러나, 효과적인 자세 교육 및 교정을 위해서는 장시간 동안의 관찰이 선행되어야 하며, 현장에서 실시간으로 피드백을 제공하는 것이 필요하기 때문에, 상당량의 인적, 시간적, 경제적 비용이 소모된다.

이에 본 연구에서는 아동의 부적절한 앉은 작업 자세 문제에 대해 다음과 같은 방안을 도출함으로써, 문제를 해결하고자 하였다: 1) 새로운 학생용 책상 및 의자의 높이 시스템 개발, 2) 새로운 학생용 책상 및 의자의 높이 선택 가이드라인 개발, 3) 새로운 앉은 자세 모니터링 시스템 개발. 뿐만 아니라, 위와 같은 해결 방안 도출 사례를 바탕으로, 다양한 착석 작업에서의 부적절한 작업 자세 문제 해결을 위한 알고리즘 기반의 체계적 접근 방안을 제시하고자 하였다.

제 3 장에서는 총 4014 명의 한국 아동의 인체측정학적 데이터를 활용하여 현재 한국 초등학교에서 사용되고 있는 책상 및 의자의 높이 시스템의 인체측정학적 적합성을 평가하였다. 그 결과, 책상의 경우 약 절반 정도의 아동

만을 수용할 수 있으며, 그 원인이 책상 밑 서랍의 존재인 것으로 밝혀졌다. 의자의 경우 대부분의 아동을 수용할 수 있지만, 불필요한 높이 단계가 존재하는 것으로 밝혀졌다. 이러한 문제를 해결하기 위해, 알고리즘을 활용한 접근법을 통해 새로운 책상 및 의자의 높이 체계를 개발하였다. 그 결과, 새로운 책상의 높이 체계는 수용률을 현저히 높일 수 있으며, 새로운 의자의 높이 체계는 보다 적은 높이 단계로도 모든 아동을 수용할 수 있는 것으로 확인되었다.

제 4 장에서는 현재 사용되고 있는 책상 및 의자 높이 선택 가이드라인의 적합성을 평가하였다. 또한, 아동들이 인체측정학적으로 적합한 책상 및 의자의 높이를 스스로 선택할 수 있는지 평가하였다. 첫 번째 연구에서는, 현재 높이 시스템으로 수용할 수 있는 2005 명의 아동의 인체측정데이터가 활용되었으며, 현재 사용되고 있는 가이드라인에 따른 권장 높이가 인체측정학적으로도 권장될 수 있는지 평가하였다. 두 번째 연구에서는, 총 36 명의 아동으로부터 얻은 인체치수데이터를 활용하여, 그들이 자발적으로 선택한 책상 및 의자의 높이가 인체측정학적으로 권장될 수 있는지 평가하였다. 첫 번째 연구 결과, 현재 사용되고 있는 가이드라인으로는 전체 아동의 약 4 분의 3 정도만을 인체측정학적 권장 높이로 유도할 수 있는 것으로 밝혀졌다. 두 번째 연구 결과, 실험에 참여한 아동의 약 4분의 1 정도만이 자발적으로 인체측정학적 권장 높이를 선택한 것으로 밝혀졌다. 이러한 문제를 해결하기 위해, 머신 러닝 기법을 활용하여 새로운 높이 선택 가이드라인을 개발하였다. 그 결과, 새로운 가이드라인을 활용할 경우 더

많은 아동들이 인체측정학적으로 권장되는 책상 및 의자의 높이를 선택할 수 있음을 확인하였다.

제 5 장에서는 압력센서 기반의 앉은 자세 모니터링 시스템을 개발하였다. 시스템 개발을 위해 압력 분포 센싱 매트를 자체 제작하였으며, 이를 좌판 쿠션에 삽입한 후 아동들로부터 9 개 앉은 자세에 대한 압력 분포 데이터를 수집하였다. 자세 분류를 위해서는 딥러닝 기법 (convolutional neural network)이 활용되었다. 시스템의 사용 시나리오를 고려하여 총 3 가지 분류 실험이 이루어졌는데, 첫 번째는 사용 이력이 있고 신원 확인 가능한 사용자의 사용을 가정한 실험이었고, 두 번째는 사용 이력이 있지만 신원 확인이 불가능한 사용자의 사용을 가정한 실험이었고, 세 번째는 사용 이력이 없는 사용자의 사용을 가정한 실험이었다. 실험 결과, 시스템이 첫번째 실험에서는 99.66%, 두번째 실험에서는 99.40%, 세번째 실험에서는 77.35%의 자세 분류 정확도를 보이는 것으로 확인되었다. 또한 세번째 실험 결과, 시스템이 왼쪽 또는 오른쪽으로 기울인 자세는 비교적 높은 정확도로 인식 가능하나, 바른 자세, 앞으로 기울인 자세, 양반 다리 자세의 경우에는 비교적 부정확하게 인식하는 것으로 밝혀졌다.

제 6 장에서는 결론에 이르러 본 논문의 주요 결과물과 의의, 한계점에 대한 논의와 함께, 3, 4, 5 장에서 수행된 연구 방법들을 종합하고 일반화 시킴으로써 다양한 착석 작업에서 발생하는 부적절한 작업 자세 문제를 해결하기 위한 프로세스를 제안하였다.

본 논문에서는 현재 한국 초등학교에서 사용되고 있는 책상 및 의자의 디자인과 그들의 선택 가이드라인에 문제가 있으며, 아동들이 인체측정학적으로 적합한 책상 및 의자 사용법에 대한 지식이 부족함을 확인하였다. 이에 따라 개발된 책상 및 의자의 높이에 대한 디자인 및 선택 가이드라인은 보다 많은 아동들이 인체측정학적으로 적합한 책상 및 의자를 사용케 함으로써, 아동의 앉은 자세 향상에 직접적으로 도움이 될 수 있을 것으로 기대된다. 개발된 앉은 자세 모니터링 시스템 또한 현장에서의 자연스러운 자세를 비침습적으로 관찰할 수 있을 뿐만 아니라, 실시간 교정 시스템 개발에 활용될 수 있어, 아동의 바른 자세 습관 형성에 기여할 수 있을 것으로 예상된다. 마지막으로, 본 논문에서 활용된 연구 방법들은 아동의 앉은 자세 뿐만 아니라, 다양한 착석 작업에서의 작업 자세 문제를 해결하는데 적용 될 수 있을 것으로 기대된다.

주요어: posture, working posture, workstation design, anthropometric design, children, posture classification, monitoring system, machine learning, deep learning

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