Redesigning Indonesian classroom furniture to ensure ease of transport by elementary school students

ルル, プルワニングラム

https://doi.org/10.15017/1670408

出版情報：九州大学, 2016, 博士（芸術工学）, 課程博士
バージョン：

Redesigning Indonesian classroom furniture to ensure ease of transport by elementary school students

Lulu Purwaningrum

Abstract

The objective of this dissertation was to determine the proper weight, shape, and holding position of Indonesian elementary school chairs, for easy carrying, lifting, and turning by children aged 6–9, to encourage active learning. Three studies were conducted to examine 1) the effects of elementary school furniture weight and children's age on the performance of three tasks—carrying a chair, carrying both a chair and a desk, and lifting a chair onto a desk; 2) methods of transporting and grasping a chair; and 3) the effectiveness of implementing chair modifications and different holding positions. The first study found that chair features, and especially chair weight, strongly influenced children's performance in transporting furniture. Weight guidelines of furniture for elementary school children aged 6–9 were proposed. It was recommended that the weight of Indonesian elementary school furniture, which was too heavy for children aged 6–9 and especially children of younger ages, be decreased to encourage active learning. The second study identified preferred methods of carrying a chair and popular grasping patterns for carrying a chair, and lifting and turning a chair. These patterns should be considered during the redesign of heavy Indonesian elementary school furniture to ease transport, without having to decrease weight. The third study implemented two strategies based on findings of the second study about Indonesian elementary school chairs. The effectiveness of the strategies was then evaluated. The strategies were 1) modifying the shape of the chair to have a curved rectangle edge and be the proper size for a child's grasp, and 2) carrying a chair in the lower holding position (LHP) or higher holding position (HHP). The chair modification and LHP significantly reduced task time, and significantly decreased activity of the deltoid middle fiber muscle. However, for lifting and turning a chair onto a desk, these strategies did not eliminate the influence of the excessive weight of the chair and discouraged easy task completion. In conclusion, Indonesian elementary school furniture is too heavy and large for young children to transport. Two effective strategies were provided that did not require decreasing the chair's weight, and could improve the ease of carrying the chair. The findings of this dissertation may be useful to propose further research for redesigning Indonesian elementary school chairs to encourage active learning, which will lead to improvements in education quality in Indonesia as well as other developing countries.

Table of Contents

List of Table

List of Figure

Chapter 1

General introduction

1. Active learning in the classroom and school furniture

It is widely believed that active learning approaches have a positive impact in current educational systems. Finding of previous studies have shown that applying this type of approach in the classroom can significantly increase student enthusiasm [1], and improve the quality of both the learning process and learning outcome [2-8]. Active learning as a learning process derived from Dewey [9], Piageat [10], Vygotsky [11], and Ernest [12] theories that students construct a knowledge concept through their own learning activities, namely, learning by doing and experiencing. Thus, obtaining knowledge does not only depend on the teacher, but also on actively building knowledge, rather than being passive [9]. Furthermore, UNICEF [13] recommended the implementation of active learning, for which the student is the center of the learning process, in classrooms to encourage the quality of the learning process. Since quality of education involves the learner, learning environment, content, processes, and outcome quality [8], it is necessary to encourage active learning implementation to improve the quality of education.

In the learning process, children not only need to build their own concepts, but also need to share or communicate their understanding to others [11]. This requires students to be active in class, such as by speaking, observing, performing tasks, and collaborating with friends. According to another definition, students are active physically and mentally in an active learning process [3]. Accordingly, classroom layouts should be arranged appropriately based on the teaching purpose [14-16], and can significantly affect improvements in the learning process as well as learning outcomes [14-19]. For example, to improve social interaction among students, furniture should be arranged in a semi-circle. Furthermore, students will more actively ask questions within a row and column arrangement [14-16]. Since according to the active learning principle students should be active mentally and physically to construct knowledge [3, 9-12], having children arrange furniture themselves may encourage the learning process. Even though teachers may give instructions on how children should arrange the furniture, children will be stimulated to initiate further action such as the technical aspects of the arrangement. Therefore, to encourage furniture arrangement by children for active learning purposes, furniture should be easy for them to transport, which also would reduce the time required to arrange the classroom layout.

2. School furniture in developed countries

When classroom furniture is arranged for active learning, various tasks are carried out by children. For example, chairs and desks are often carried to make table layouts for group work and discussion. For other activities, chairs and desks are carried together and moved against the classroom wall, when a large empty area is needed in the center of the classroom. Before doing these tasks, chairs are sometimes lifted and turned onto desks. Thus, in order to accommodate these task demands, furniture should be light enough to transport, and furniture weight should be appropriately matched to the carrying abilities of children at different ages.

Currently, only developed countries have been able to design elementary school furniture to meet active learning demands, due to their sufficient budgets. Typical furniture has been produced according to size standards by age [20]. In almost all developed countries, standard size dimensions have been matched to age ranges and children's body dimensions; however, in some developed countries such as China [21-22], the United States [23], New Zealand [24], and Taiwan [25], sizes have not been matched to children's body dimensions. Size standards for each age range [20] may indicate the appropriate weight for each age. Moreover, the development of moving furniture was proposed by Breitecker [17], such as the swivel chair, and in some developed countries this concept has been applied in classrooms (Germany, the United States). However, this chair may not be easy to carry and move, and lift and turn by children. Thus, in order to encourage ease of furniture transport and the possibility of active movement in class, it may be more appropriate to use furniture properly sized by age range [20].

The ISO 5970 [20] standards have shown that demands of active learning can be met. Dimension standards by age range may be matched to children's weight in each age range. For example, in Japan, elementary school chairs and desks are chosen according to children's age ranges as well as their body dimensions. Given that children often complete tasks such as carrying chairs, carrying chairs and desks together, and lifting and turning chairs, weight standards are necessary for manufacturing as well as ease of furniture transport.

3. School furniture in developing countries

The provision of proper elementary school furniture for active learning is related to improvements in the quality of education, and is affected by government education policies and factual conditions. UNESCO [26] reported that the quality of education in developing countries still remains inadequate. Economic problems of developing countries, especially low and middle-income countries, are the main obstacle to local governments providing proper learning environments [26] including furniture. Therefore, since furniture is a factor to improve the quality of education, optimizing furniture in developing countries should be addressed.

Furniture with standard sizes for each age range of children [20] may be easy to move and arrange to encourage active learning. However, in developing countries, a mismatch has been found between furniture and students' body dimensions. Adewolo and Isedowo [27] reported that the dimensions of desks and chairs in a Nigeria elementary school did not fit school children aged 5-12. The same results also were found in Chile [28], Vietnam [29], Greece [30-31], Egypt [32], India [33], Croatia [34], Iran [35], Serbia [36], Turkey [37], and Indonesia [38-40]. Since proper weights may be derived based on proper furniture sizes for different age ranges, mismatched sizes of furniture in developing countries may indicate that weights also were not appropriate for children in each age range.

Indonesia, as a representative developing country, has constraints with respect to elementary school furniture. Improvements in elementary school furniture will improve the quality of education in Indonesia, which is one of five missions of the Ministry of Education and Culture's strategic plan for 2015-2019 [41]. However, Indonesian furniture, which does not match children's dimensions [38-40], may not be of proper weight to be easily moved and arranged for all age ranges of children. Moreover, strategic planning by the Indonesian Ministry of Education and Culture from 2015 to 2019 [40] asserts that it is necessary to improve student involvement in active learning activities. In fact, the Indonesian Ministry of Education and Culture has a guideline requiring that Indonesian elementary school chairs should be easy for children to transport, to promote active learning [43]. Moreover, the guideline states that elementary school chairs should be provided in two sizes for lower grades (1, 2, and 3) and higher grades (4, 5, and 6) [43], to accommodate children's body dimensions and their ability to move the chair. However, it is difficult to implement this guideline because the Ministry of Education and Culture does not obligate schools or local government to execute and implement the standard.

Previous researches show that furniture has been produced manually in conventional factories or home businesses, with workshops located in extended houses [38-40]. In these workshops, complicated and uniform shapes of the furniture could not be created (complicated and precise shapes of the furniture could not be produced easily). Furthermore, to provide inexpensive furniture, low-wage Indonesian woodworkers, and local rough wood materials were employed. A pilot study indicated that this furniture is rustic, with sharp edges, and a thick component. Moreover, the improper size of this furniture for younger children makes it heavy for them. Given the limited budget of the Indonesian government for school environments, and the budgetary priority of school furniture [41], this product was chosen to meet quantity but not quality demands.

Therefore, based on limitations in Indonesian school furniture manufacturing and the need to meet active learning directives, alternative strategies are needed to improve the ease of transport of furniture without decreasing weight, such as modifying the shape or teaching the proper way for furniture to be held.

4. The ability of children to carry, lift, and turn chairs

Since Indonesian furniture is unfit for children in each age range [38-40], it may be excessively heavy for them. The physiological cost of walking and the load on leg muscles increase with increases in load weight [44]. Moreover, carrying weight should be proportional to children's body weight [44-46]. Studies about maximum loads for carrying, lifting, and turning for adults largely concern the biomechanics field [47-51]. For adults, the maximum weight in a carrying task should be lower than 10% of body weight [52], and the maximum weight in a lifting and turning task involving standing straight for eight hours should be 34.1% and 25.7% for males and females, respectively [52]. While numerous load weight studies have been conducted related to a biomechanics point of view to reduce excessive loads [53-58], to our knowledge, no studies have been conducted regarding maximum load weights for children. Therefore, to expand practical biomechanics to improve quality of life at all ages, it is necessary to obtain maximum elementary school furniture weights for carrying, lifting, and turning.

Furthermore, there are a range of children's body dimensions in each age range. This could explain how standard school furniture sizes [20], which are based on children's body dimension in each age range, can be implemented for certain age ranges. Age ranges are characterized not only by body dimensions, but also by weight. Body weight and age have a strong relationship, such that the body weight of children normally increases with age [59-60]. Since the ability to carry a load of a certain weight relates to body weight, children of increasing age will have increased ability to carry weight. Therefore, the weight of school furniture should correspond to children's ages as well as their body weights.

5. General objectives and research plan

The general objective of this study was to determine the proper weight, shape, and holding position of Indonesian elementary school furniture, and chairs in particular, for easy carrying, lifting, and turning by children aged 6-9, to encourage active learning in the classroom. Three studies were conducted to achieve this objective. The first concentrated on the weight of the chair. The second focused on the method to transport the chair. These studies provided guidelines on the proper weight and shape of chairs for children aged 6-9. The third study was conducted to evaluate the effectiveness of the recommendations of the first and second studies.

6. Structure of the dissertation

This dissertation was divided into five chapters:

Chapter 1: **General introduction**

This chapter describes the background of the Indonesian elementary school furniture problem, including conditions associated with the problem of difficult transport that discourages active learning activities in the classroom. This chapter explains the general study objective and brief research plan.

Chapter 2: **Effect of furniture weight on carrying, lifting, and turning of chairs and desks among elementary school children**

In this chapter, a study published in PLoS ONE (DOI: 10.1371/ journal.pone. 0128843; Lu'lu' Purwaningrum, Kyotaro Funatsu, Jinghong Xiong, Cucuk Nur Rosyidi, Satoshi Muraki) on June 8, 2015. The objective of this study was to investigate the effects of elementary school furniture weight and child's age on the performance of three carrying tasks (carrying a chair, lifting and turning a chair onto a desk, and carrying both a chair and a desk together) from an ergonomics point of view.

Chapter 3: **Study of children's methods of grasping and carrying chair to redesign elementary school chairs for easy carrying, lifting and turning**

The objective of this study was to investigate children's methods of carrying a chair as well as lifting and turning it onto a desk.

Chapter 4: **The effectiveness of a proper shape and holding positions of the elementary school chair to encourage the student transporting a chair easily**

The objective of this study was to evaluate the effectiveness of shape modifications of Indonesian chairs, to allow a proper holding position for carrying a chair, and lifting and turning a chair onto a desk for children aged 6-8.

Chapter 5: General discussion

This chapter summarizes the results of Chapters 2-4, including recommendations for the design of elementary school chairs that are easy to carry, lift, and turn for children.

Chapter 2

Effect of furniture weight on carrying, lifting, and turning of chairs and desks among elementary school children

1. Introduction

It has long been noted that elementary schools should provide desks and chairs that are easy for students to move and carry. School furniture (e.g., chairs and desks) that is easy to move and carry could help to improve the quality of education [14-17]. Previous studies have suggested that seating arrangements should be changed on a regular basis, because they may have a significant influence on student's behaviors [14-16]. For example, furniture in rows and columns may lead students to ask more questions, whereas semi-circle configurations may encourage social interaction among students [14]. Considering the limited carrying and lifting capabilities of children, and that lighter or proper-weight furniture requires less effort to move, use of this type of furniture could save time as well as reduce the risk of injury.

Increasing the weight that one carries increases the physiological cost of walking, and the load on leg muscles [44]. Studies have suggested that the weight of backpacks carried by children should be proportional to their body weight [44-46, 61]. The body weight of children normally increases with age [59, 60, 62]. Therefore, the weight of school furniture should correspond to children's ages and body weights.

Some solutions have been proposed with regard to this issue. Breithecker [17] introduced a new swivel chair design using castors, named the "ergo dynamic" or "movement ergonomic" chair. This chair can be easily moved by children in the classroom [17]. In addition, the attention and concentration of students using these chairs have been shown to improve by over 70%, compared with students using traditional chairs [17]. Although this design provides an easy-to-move chair, developing countries have difficulty implementing this change, because of budgetary concerns and limited manufacturing techniques.

In developed countries such as Australia, Japan, and Scotland, elementary school chairs and desks are lighter, and may be easily carried and moved by all children (Fig. 2.1); However, weight guidelines still need to be better applied prior to manufacturing. Many researchers have investigated appropriate furniture for elementary school children in their respective countries [21-25, 27-40], but these studies have not focused on weight issues. In Japan, school furniture dimensions are regulated based on ISO 5970 [20], so that furniture appropriate for children of certain body dimensions and age ranges is produced. However, weight guidelines are needed for manufacturing.

Fig. 2.1. Chairs and desks of elementary school in Australia, Japan, and Scotland elementary schools.

In developing countries such as Nigeria, Malaysia, Indonesia, and Vietnam (Fig. 2.2), the weight of elementary school furniture has not been sufficiently considered. Since there are insufficient studies on furniture weight, children may carry chairs and desks that are too heavy for them. In Indonesia, the Ministry of National Education has a regulation that elementary school chairs must be easily carried by children [43]. In addition, the desired dimensions (including weight) of school furniture differ between grades 1-3 and grades 4-6 [43]. However, in most developing countries, across every age and grade in elementary schools, chairs have uniform dimensional standards [65, 66]. This may discourage movement of chairs and desks for classroom activities.

Fig. 2.2. Chairs and desks of elementary schools in Indonesia, Vietnam, Malaysia and Nigeria.

Taking all of the above finding into account, it is necessary to propose a weight guideline for elementary school furniture that is proportional to children's body dimensions at certain ages. The present study investigated the effects of elementary school furniture weight and children's age on performance of three tasks-carrying a chair, carrying both a chair and a desk, and lifting a chair onto a desk. This study also compared the difficulty of these tasks for Indonesian and Japanese furniture.

2. Materials and methods

2.1. Participants

Healthy Indonesian and Japanese children (N = 42) who could understand the experimenters' instructions participated in this study. The Indonesian children included 6 boys and 11 girls, and the Japanese children included 12 boys and 13 girls. Their ages ranged between 6.0 and 9.9 years and they were categorized into four age-range groups: 6 (6.0-6.9), 7 (7.0-7.9), 8 (8.0-8.9), and 9 (9-9.9) years. In both Indonesia and Japan, children go to elementary school for six years, starting at age 6. The age range of the participants corresponded to the lower and middle grades (first to fourth year) of elementary school. Table 2.1 presents the number of participants by age-range group, sex, and nationality.

Before the experiment, participants' parents signed informed consent forms. This study was approved by the ethics committee of the Faculty of Design, Kyushu University, Japan (Approval Number: 125).

Table 2.1. Number of participants

Age group (Age range, years)	Indonesian (N)		Japanese (N)	
	Boys	Girls	Boys	Girls
6 (6–6.9)	1	2	5	1
7 (7–7.9)	1	3	4	2
8 (8–8.9)	3	4	3	7
9 (9–9.9)	1	2	0	3
Total	6	11	12	13

2.2. Experimental instruments

Representative furniture from Indonesian and Japanese public elementary schools were used as the main equipment in this experiment, including one Indonesian chair, two Japanese chairs, and one Japanese desk.

2.2.1. Chairs

Two Japanese (Chairs A and B) and one Indonesian (Chair C) chairs were used to create three different chair weight conditions (Fig. 2.3, Table 2.2). In Japan, some sizes of chairs and desks (proportional to student height) based on ISO 5970 [20] are most readily available in elementary schools. This experiment employed two sizes of Japanese chairs. Chairs A and B were Size 2 (340 mm width x 290 mm depth x 300 mm seat height) and Size 3 (360 mm width x 290 mm depth x 340 mm seat height), respectively. Chairs A and B were appropriate for students whose height ranged between 117 and 130 cm, and between 131 and 144 cm, respectively. Although the material was the same for both chairs, the weights were different due to the size difference (Chair A: 3.2 kg, Chair B: 3.9 kg).

Fig. 2.3. Chairs for the experiments. Chairs A and B are Japanese elementary school chairs; Chair C is a typical Indonesian elementary school chair.

Table 2.2. Dimensions of Indonesian and Japanese chairs.

Dimension	Chair		
	A	B	C
Seat height[a] (mm)	300	340	420
Weight (kg)	3.2	3.9	5.0

[a]Distance from the seat to the bottom of the chair.

In contrast, in Indonesia, there is no precise standard for school furniture design for each age. Accordingly, the ordinary elementary school chair had a seat height and weight of 420 mm and 5 kg, respectively (Table 2.2). This is a typical chair used in most public Indonesian elementary schools [38-39, 43, 67]. According to a survey regarding chair weights in 11 public Indonesian elementary schools (prior to this experiment) [39], 5 kg was among the lowest range of chair weights in Indonesian elementary schools. The seat height of the chair was in the same range as chairs generally used in Indonesian elementary schools (380-450 mm) [38-39, 43].

2.2.2. Desks

Only a Japanese elementary school desk was used in this experiment (Fig. 2.4). This desk was for children whose height ranged from 131 to 144 cm (Size No. 3 of Japanese elementary school desk), and met ISO 5970 [20]. The height and weight of the desk were 580 mm and 8.4 kg, respectively (Table 2.3). The Indonesian desk was simulated using the Japanese desk with additional height and weight. The height and weight of the desk was based on the typical Indonesian elementary school desk, which was 55-75 cm [38-39, 43]. In lifting and turning the chair, additional height was added using a box (height: 100 mm) (Fig. 2.4). This was an adequate simulation of an Indonesian desk for this task, because the main goal was to investigate the effect of the chair weight. In carrying a chair and desk together, additional weight created by placing 4.6 kg of iron in the desk drawer was adequate to simulate the heavier Indonesian desk.

Fig. 2.4. The Japanese desk without additional height (left) and with additional height (right).

Table 2.3. Weights for various combinations of carrying both a chair and a desk.

Furniture	Combination A	B	C	D
Chair (kg)	3.2	3.9	5.0	5.0
Desk (kg)	8.4	8.4	8.4	8.4
Additional weight (kg)	-	-	-	4.6
Total weight (kg)	11.6	12.3	13.4	18.0

2.3. Experimental tasks, conditions, and procedures

The experiment was conducted in a large flat space over six days in February and March 2013. Participants performed three different tasks: 1) carrying a chair, 2) turning and lifting a chair on a desk, and 3) carrying both a chair and a desk together. Before each task, we gave participants brief instructions about how to complete each task, and time for practice. To prevent injury, participants wore non-slip work gloves and shoes. In addition, we instructed them to stop the task immediately if they felt it was impossible or dangerous to continue. During the task, an adult stood beside the participants for safety.

Participants performed tasks from lighter/smaller to heavier/larger furniture, in order to prevent injury, and to allow participants to judge easily whether they could perform the next task level. After each task, an experimenter ensured that factors such as pain, fatigue, lack of motivation, etc. would not influence performance of the next condition. During each task, participants' movements were recorded using a digital video camera (Panasonic, HC-V 300 M, Japan) at 30 frames per second.

2.3.1. Task 1: Carrying a chair

This task involved bringing each chair (A, B, and C) from the start to finish line (a 3 m distance). A chair was placed sideways behind the start line, and participants sat on the chair to wait for the start command. After we gave a signal to start, they stood up from the chair, raised the chair with their hands, carried it toward the finish line, and put it down on the floor beyond the finish line. Before tasks, we instructed them that they 1) could hold any part of the chair, 2) should not push or slide the chair on the floor, and 3) should walk at an ordinary speed during the task.

Fig. 2.5. Task 1: Carrying a chair a distance of 3 m. Step 1: start position; Step 2: standing up (start time); Step 3: carrying the chair; Step 4: putting the chair down (finish time).

2.3.2. Task 2: Lifting and turning a chair upside down

This task involved turning a chair upside down and putting it on a desk. In this task, three chair weights (Chairs A, B, and C) and two desk heights (standard desk height: 580 mm, higher desk height: 680 mm) were employed.

A chair was placed in front of the desk as indicated in Fig. 2.6. First, the participant sat on the chair to wait for the start command. After the start command, the participant stood up from the chair, turned the chair upside down, and put it on top of the desk, as shown in Fig. 2.6. Participants could hold any part of the chair, and they could rotate the chair on the floor if necessary.

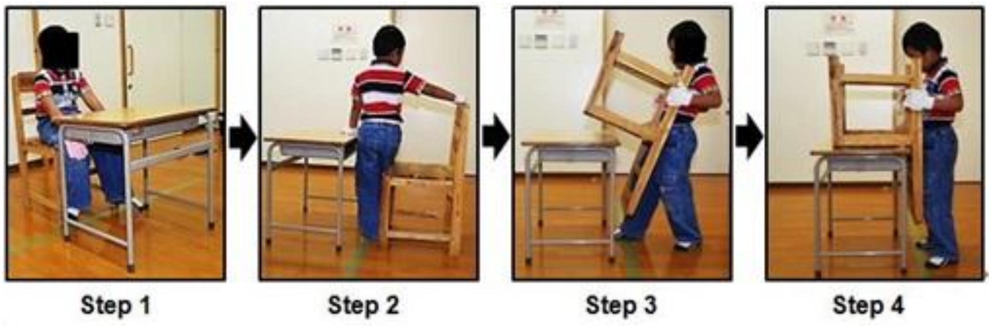


Fig. 2.6. Task 2: Turning a chair upside down. Step 1: starting position; Step 2: standing up (start time); Step 3: turning the chair upside down; Step 4: putting the chair on the desk (finish time).

2.3.3. Task 3: Carrying both a chair and a desk

This task involved moving a desk with a chair, which was placed upside down on top of the desk (Fig. 2.7), from the start to finish line (a 3 m distance). In this task, four conditions of different total weight (11.6, 12.3, 13.4, and 18 kg) were employed using three chairs (Chairs A, B, and C), a desk, and additional weight as specified previously (Table 2.3).

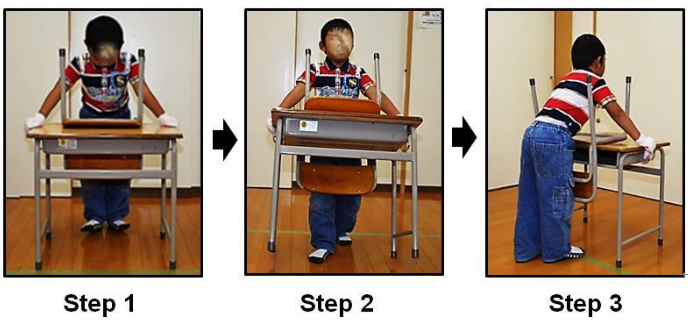


Fig. 2.7. Task 3: Moving a chair and a desk together. Step 1: Starting position (start time); Step 2: carrying; Step 3: placing on the floor (finish time).

A desk was placed facing forward behind the start line. First, the participant stood in front of the desk, and held the sides of the desk top with both hands while waiting for the start command. After the start command, participants carried the desk and chair to the finish line, and placed it on the floor beyond the finish line. Before the task, participants were instructed to walk at a normal speed and to push or slide the desk across the floor.

2.4. Measurements

2.4.1. Physical characteristics of participants

Before the experiment, height, weight, body mass index (BMI), and grip strength were measured. Grip strength was measured for both hands using a digital handgrip dynamometer (Takeikiki, A 5401, Japan).

2.4.2. Task time

The time taken to complete each task (task time) was measured using frame-by-frame playback of the recorded video. In Task 1, the start time was the moment when one chair leg bottom was raised off the floor, and finish time was when one chair leg bottom touched the floor. For Task 2, the start time was when one chair leg bottom was lifted, and the finish time was when the chair’s seat was placed on the table. Lastly, for Task 3, the start time was when one leg bottom of the desk and chair was raised, and finish time was when one was placed on the floor.

2.4.3. Successful and unsuccessful lifting and turning of the chair

In the task involving lifting and turning a chair onto the desk, we judged that children were successful if they could complete the task without dropping the chair, without stopping for a while in the middle of the task, and without putting themselves in danger. Dangerous situations were identified as those in which children carried the chair with an unstable grip and they were at risk of dropping it.

2.5. Statistical analysis

Statistical analyses were performed using IBM SPSS Version 21.0 (2012) for Windows, Chicago, USA. Descriptive results were presented as means and standard deviations. Two-way analysis of variance (ANOVA) was used to identify differences in physical characteristics related to sex and nationality. Pearson correlation coefficients were calculated to analyze the relationship among children's physical characteristics, between children's physical characteristics and task time, and between chair type and task time. A repeated measures one-way ANOVA was employed to compare task time of the three chair types in the chair-moving task, followed by post-hoc pairwise Bonferroni-corrected comparison tests for significant differences among chair types. The exact chi-square test was used to compare success rates among task conditions for the lifting and turning task and the moving a chair and desk together task [68,-69]. The level for significance was set at 0.05.

3. Results

3.1. Physical characteristics

Table 2.4 presents means and standard deviations of physical characteristics of participants, separated by sex and nationality. Two-way ANOVA revealed no significant effects of sex or nationality. For all participants (N = 42), age showed a significant positive correlation with height ($r = 0.762$, $p < 0.01$), weight ($r = 0.547$, $p < 0.01$), and grip strength ($r = 0.535$, $p < 0.01$).

Table 2.4. Physical characteristics of participants

Participants	Indonesian		Japanese		All
	Boy (N = 6) M ± SD	Girl (N = 11) M ± SD	Boy (N = 12) M ± SD	Girl (N = 13) M ± SD	N = 42 M ± SD
Age (years)	7.5 ± 1.0	7.6 ± 1.0	7.4 ± 0.8	8.3 ± 0.8	7.8 ± 1.0
Height (cm)	122.3 ± 4.6	122.7 ± 7.4	119.2 ± 7.9	126.0 ± 6.0	122.7 ± 7.1
Weight (kg)	25.6 ± 5.1	23.8 ± 3.1	22.8 ± 2.7	26.2 ± 3.1	24.5 ± 3.5
BMI[a] (kg/m^2)	17.2 ± 2.58	15.9 ± 1.9	16.0 ± 1.1	16.4 ± 1.2	16.3 ± 1.7
Grip strength (kgf)	9.5 ± 1.7	8.7 ± 1.6	8.5 ± 2.0	10.0 ± 2.8	9.23 ± 2.2

[a]Body mass index.

3.2. Carrying a chair

All participants successfully completed the task of carrying a chair for all chair conditions. Fig. 2.8 displays the task time for carrying only a chair a distance of three meters. The task time for Chair C was significantly longer than that of Chairs A and B ($p < 0.05$). A repeated measures one-way ANOVA showed a significant effect of chair type on task time ($p < 0.01$). Post-hoc tests using the

Bonferroni correction revealed a significant difference between Chairs A and C, and between Chairs B and C ($p < 0.05$). Fig. 2.9 illustrates the relationship between participant age and task time for each chair condition. There were significant negative relationships between these variables for Chair B ($r = -0.368$, $p < 0.05$) and C ($r = -0.347$, $p < 0.05$), but not for Chair A. However, task time was not significantly correlated with other physical characteristics (height, weight, BMI, and grip strength).

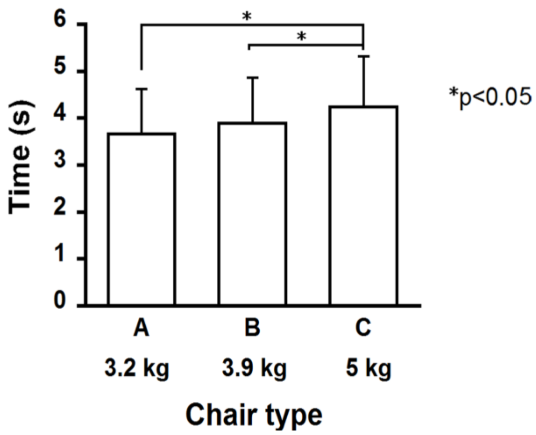


Fig. 2.8. Task time for carrying only a chair.

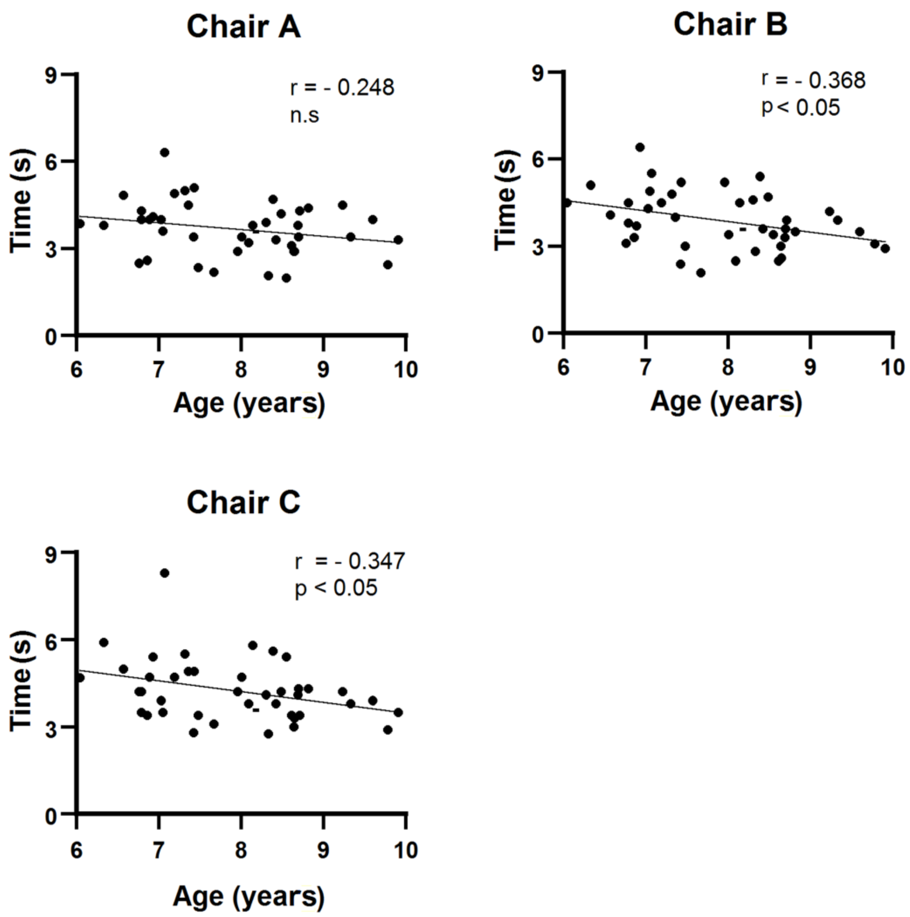


Fig. 2.9. Relationship between participant age and task time for each chair condition.

3.3. Lifting and turning a chair

In both desk height conditions, the exact chi-square test revealed significant differences in success rates of lifting and turning a chair among the three chair conditions ($p < 0.01$). Chairs A and B showed success rates over 60%, whereas Chair C showed a lower success rate (around 20%) for both desk height conditions (Fig. 2.10). In contrast, a significant effect of desk height on success rate was not found for any chair condition.

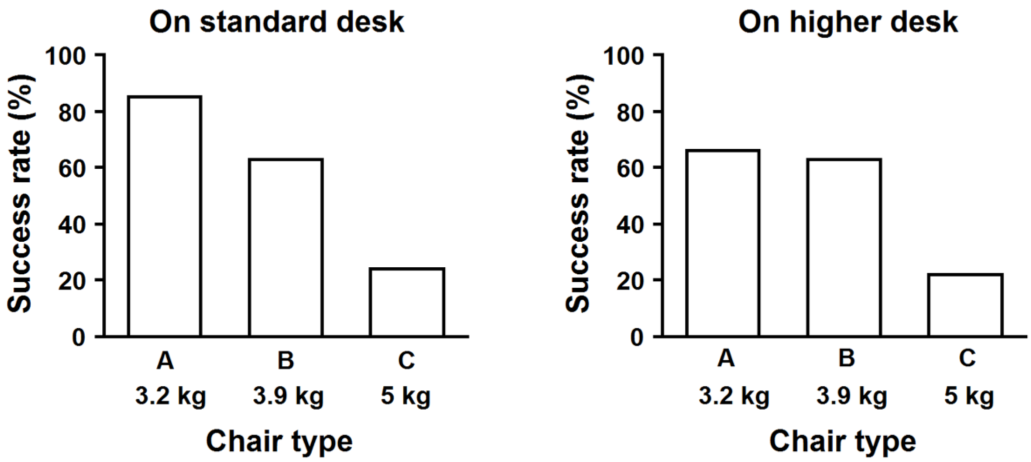


Fig. 2.10. Success rates by chair type for lifting a chair on a standard/higher desk. Exact chi square test: standard desk: $p < 0.01$; higher desk: $p < 0.01$.

Fig. 2.11 presents the effects of chair type and age on success rates for turning and lifting a chair in both desk height conditions. Success rates increased with age for all combinations of chair type and desk height, except for Chair C on a standard height desk. Participants aged 9 years attained a success rate of 100% for Chairs A and B in both desk height conditions. For participants aged 8 years, the success rate was significantly affected by chair type for both desk heights. Approximately 80% succeeded with Chairs A and B, but success rates dropped dramatically to approximately 20% for Chair C. For participants aged 7 in both desk height conditions, success rates gradually decreased from Chair A, to B, and to C, although the effect was of borderline significance in the standard height condition ($p = 0.051$). In addition, the success rate of participants aged 6 years showed a significant effect of chair type only for a standard desk. Although a high success rate (approximately 60%) was shown for Chair A and a standard desk height, very low rates were found for other combinations of chair types and desk heights.

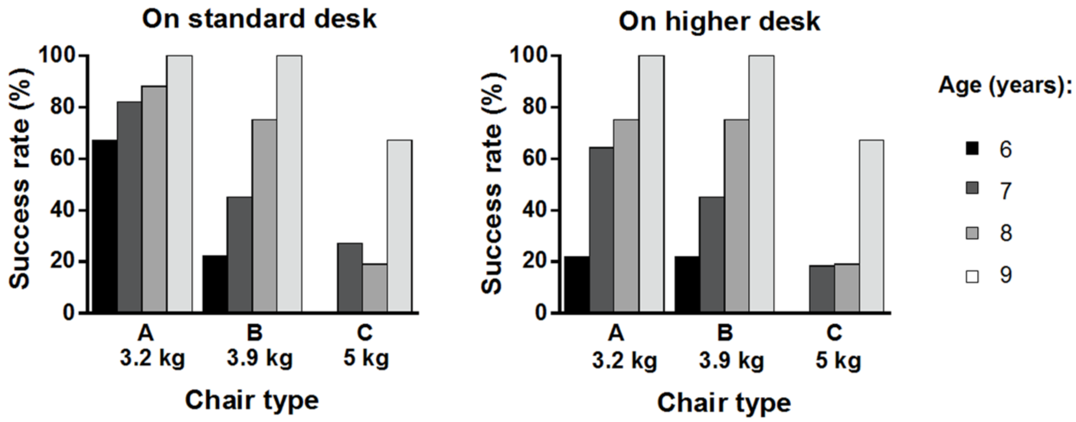


Fig. 2.11. Success rates for chair type by age for lifting a chair on a standard/higher desk. Exact chi square test among chair types. Standard desk: age 6, $p < 0.01$; age 7, $p = 0.051$; age 8, $p < 0.01$; age 9, n.s. Higher desk: age 6, n.s; age 7, n.s; age 8, $p < 0.01$; age 9, n.s.

3.4. Carrying both a chair and a desk

For the task that involved carrying both a chair and a desk, the exact chi-square test showed a significant effect of task condition on success rate ($p < 0.01$). Success rate decreased with increasing total weight of the chair and desk (Fig. 2.12). Fig. 2.13 present the effects of task condition and age on success rate. For participants aged 7 and 8, the exact chi-square test also indicated significant differences in the rate among task conditions ($p < 0.05$). Success rates decreased with increasing total weight of the desk and chair, although success rates were nearly 100% for combinations A and B in children aged 8. However, this trend was not found for participants aged 6 and 9. For participants aged 9, success rates higher than 80% were observed for all conditions. In contrast, the success rate for participants aged 6 was lower (approximately 20%) for all conditions.

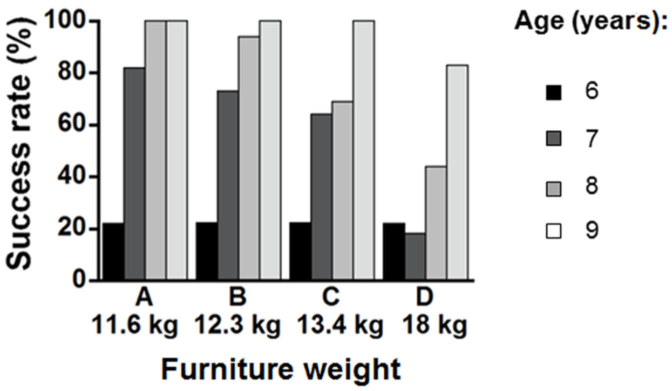


Fig. 2.12. Success rates by four furniture weights for carrying a chair/desk together. Exact chi square test: $p < 0.01$.

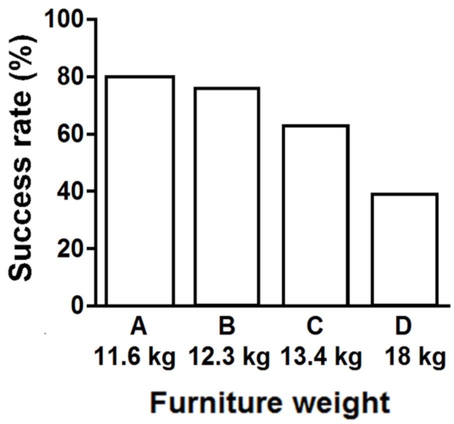


Fig. 2.13. Success rates for four furniture weights by age group for carrying a chair/desk together. Exact chi square test: age 6, n.s.; age 7, $p<0.05$; age 8, $p<0.05$; age 9, n.s.

4. Discussion

4.1. Effects of sex and ethnic groups on physical measurements

This study compared Japanese and Indonesian chairs, used in their respective countries, and involved children of Japanese and Indonesian ethnicity. Given that

Japanese children are familiar with Japanese chairs, they would be expected to perform better with Japanese chairs; the same would be true for Indonesian children and Indonesian chairs. Therefore, to ensure equality, this study included children who were of Japanese and Indonesian ethnicity. Previous research has found significant effects of ethnic group on anthropological measurements in children [70-71]. Ethnicity, geography, and social conditions have been shown to influence physical characteristics [71-73]. However, the present study did not demonstrate significant differences for any measurements of physical characteristics between Indonesian and Japanese children. Moreover, according to the national anthropological database of Japanese and Indonesian individuals [38-39, 74-75], heights and weights of children aged 6 to 9 are similar for the two groups. Therefore, Japanese and Indonesian children were grouped in the present analyses.

4.2. Carrying a chair

Chairs are frequently carried for class activities in elementary schools. In the present study, the task time of Chair C was significantly longer than for the other two chairs (Fig. 2.8). The prominent features of Chair C are larger dimensions and a heavier weight. This study using the same three types of chairs observed holding positions for carrying chairs, and found two popular positions. The differences in height of the popular holding positions for Chairs A and C are 34% (height of seat back lower rail: Chair A, 410 mm; Chair C, 550 mm) and 36% (seat height: Chair A, 300 mm; Chair C, 410 mm). In contrast, the difference in chair weight is 56% (Chair A, 3.2 kg; Chair C, 5.0 kg). Thus, the weight ratio is greater than the height ratio of the chairs' holding positions. Accordingly, the longer task time—namely, the decrease in performance for Chair C, might be mainly caused by the heavier weight. This assumption is supported by findings [48-50] that heavy loads decreased walking speed of participants. Chair C is the typical type used in Indonesian public elementary schools. The heavy weight of this chair could potentially discourage dynamic class activities.

Furthermore, the present study showed a negative relationship between participant age and task time for Chairs B and C, but not Chair A (Fig. 2.9). In other words, only Chair A was suitable for younger children to carry. Chair A is produced for children whose height is between 117 and 130 cm, in accordance with ISO 5970 [20]. This range corresponds to children aged approximately 6 to 7 years in both ethnic groups [38-39, 74]. ISO 5970 was created specifically so that children could be seated with proper posture. These results suggested that an easy-to-carry chair can be produced for younger children within the guidelines of ISO 5970 [20].

On the other hand, some studies recommend that the weight of carried items should be proportional to children's body weight [44-46]. In addition, the body weight of children normally increases with age [59-61]. In the present study, however, only age (and not body weight) had a significant relationship with task time. Age is comprehensive in that it involves aspects beyond physical characteristics (height, weight, physical strength), such as comprehension, skill, experience. Therefore, age is considered the best indicator for chair carrying specifications.

4.3. Turning a chair upside down and desk height

Chairs are sometimes lifted and turned upside down in elementary schools in some countries [76]. When students clean their classroom, this task is useful to create free floor space. In order to improve the efficiency of class activities, chairs and desks are often carried together by students to the perimeter of the room, or to corridors outside the room. In Japanese elementary schools, before carrying the chairs and desks, students usually lift and turn the chair upside down on the desk. Ease of this task is affected by not only the type of chair, but also the height of the desk. Therefore, the present study focused on the effects of these two aspects of school furniture, as well as the characteristics of participants.

The success rate for this task was strongly influenced by participant age (Fig. 2.11) for both desk height conditions. Children aged 6 showed a much lower success rate for all types of chairs, compared with other older children. Moreover, even for the lightest chair (Chair A), they did not show a high success rate for either lower or higher desks (67% and 22%). Based on observations of their behavior during the task, most cases of failure seemed to be caused by not only physical characteristics (e.g., strength to lift the chair, high desk height compared to the child's height) but also insufficient understanding of how to perform the task. This is in line with Rebok et al. [77], who demonstrated that comprehension of instructions among elementary school children declines with decreasing age. Accordingly, the findings of this study suggested that in order to prevent injuries among children aged 6, they need appropriate instruction and supervision when lifting and turning even a lighter chair onto a desk.

On the other hand, among children aged 7 to 9, success rates depended on chair type as well as age. All children aged 9 succeeded at the task for Chairs A and B, but some did not for Chair C. These failures were mainly due to strength limitations, unlike for children aged 6. Children's muscle strength increases with age [78], which is consistent with the grip strength results of the present study. Nevertheless, the 5.0 kg weight of Chair C was still too heavy even for some children aged 9. For children aged 7 to 8, success rate decreased as chair weight increased and as age decreased, in both desk height conditions, except for Chair C on a standard desk.

The present study failed to show significant effects of desk height on success rates for lifting and turning a chair. Some previous studies have demonstrated an effect of destination height when humans manually lift a load from the floor [51-52]. Thus, it is not that the desk height had no effect on the ease of this task, but rather that the effect of the chair's characteristics, such as size and weight, exceeded that of the desk height.

4.4. Carrying both a chair and a desk

In the current study, the success rate of carrying a chair and desk together decreased as age decreased, and as total weight of the chair and desk increased (Fig. 2.12). Furniture Combination D simulated an Indonesian chair and desk. Children's success rate in the 6-9 year age range was much lower than in other conditions (Fig. 2.13). In a previous study of adults lifting an object to hand height in a standing straight position once during eight hours, the ratios between the maximum acceptable weight and the body weight of males and females were

34.1% and 25.7%, respectively [47]. However, in the present study, the ratio of the Combination D weight (18 kg) to children's body weight (mean: 24.5 kg) was 73.5%. To our knowledge, there are no studies investigating maximum acceptable carrying weights for children. However, the weight ratio of Combination D to children's average body weight in the study was more than twice the acceptable weight ratio for adult. Therefore, the weight of Indonesian school furniture should be decreased to make it more suitable for carrying.

Children aged 6 showed a very low success rate for this task (approximately 22%), which was much different from those aged 7 and over (Fig. 2.12). As described, the previous task (lifting and turning a chair) was also difficult for them. Accordingly, these results indicate that carrying a chair and desk together is not recommended for younger children. Meanwhile, the success rate of children aged 7 to 8 decreased with increased weight of furniture. In children aged 8, the success rate was close to 100% at and below 12.3 kg of total weight (Combination B). The chair and desk in Combination A and B are mainly produced for children of heights corresponding to those aged 6-7 and 8-9, respectively, and meet the guideline of ISO 5970 [20] (e.g., children aged 7 using Combination A, children aged 8 and 9 using Combination B) were very high. It is expected that this is a familiar task that is often performed in Japanese elementary schools. Therefore, these findings suggest that guidelines for furniture weights for this task should be provided separately according to the age of the child.

4.5. Implications, limitation and future research priorities

The present study provided useful information regarding weight guidelines of elementary school furniture for promoting classroom activities (Table 2.5). However, it is not possible to propose ideal weights for each age and task, because only a few participants of each age were included in this study, and only three types of chairs were tested. Future research should aim to develop an optimal threshold for elementary school chair weights, in order to extend the practical applications of these findings.

The findings of the present study support the need for lighter chairs to encourage more dynamic class activities. However, decreasing the weight of furniture, while still manufacturing durable and strong products, may be difficult and unaffordable for developing countries. Frail chairs may lead to injuries due to lack of quality control with regard to safety. Therefore, future research could alternatively focus on the key parts of the chair, which are usually held by children, as an effective alternative strategy to improve ease of chair transport.

Table 2. 5. Weight guidelines of elementary school chairs and desks for children aged 6–9

Arrangement activities	Weight guidelines
Carrying a chair	Although a chair weight of 5.0 kg can be carried, lighter chairs enable easier carrying. For children aged 6 to 7, chair weights at or under 3.2 kg are preferable.
Lifting and turning a chair	Lighter chairs enable the task to be performed easily. However, appropriate instruction and supervision are required for all chair types, especially for children aged 6, even if the chair is light enough。 A 5.0 kg chair weight is too heavy for all children.
Carrying a chair and desk	This task is not recommended for younger children, especially those aged 6, because of safety considerations. For children aged 8, a total weight of furniture at or below 12.3 kg is preferable. A total weight of 18.0 kg (simulated Indonesian furniture) is too heavy for all children.

4.6. Conclusions

The findings of the present study indicate that children's carrying of a chair, carrying both a chair and a desk, and lifting and turning a chair onto a desk, are strongly influenced by not only children's age, but also features of the chair, especially weight. Based on the findings of the present study, the weight guideline of furniture's for elementary school children aged 6-9 was proposed (Table 2.5). Decreasing the weight of Indonesian elementary school furniture that is too heavy for children (especially children of younger ages) is recommended to encourage dynamic class activities. School furniture size and weight should be appropriate for children’s physical characteristics. Consideration given to furniture size and weight will help to enhance children’s classroom participation and improve classroom activities, thereby leading to better quality education.

Chapter 3

Study of children's methods of grasping and carrying chair to redesign elementary school chairs for easy carrying, lifting and turning

1. Introduction

Chapter 2 showed that the Indonesian elementary school chair was too heavy for children especially for younger children. In the carrying chair, the task time of Indonesian chair (weight: 5 kg) was significantly longer than the two Japanese chairs (weight: 3.2 kg and 3.9 kg), and the younger children took longer time to finish carrying Indonesian chair than the older children. In the lifting and turning a chair onto the lower and higher desk, Indonesian chair showed a lower success rate (around 20%), and children aged six showed an extremely low success rate. Therefore, according to Chapter 2, the weight of Indonesian elementary school chair was not appropriate to the certain children's age, so that decreasing the weight of Indonesian elementary school was recommended to encourage dynamic class activities.

In developed countries, decreasing chair weight to accommodate children using light, strong, and durable materials through a qualified manufacturer might be rather easy to execute. In developing countries such as Indonesia, however, there are problems with manufacturing. A simple solution for developing countries might be to produce two types of elementary school chairs—one for ages 6-9 and another for ages 10-12. However, school furniture producers that use conventional woodworking will face production obstacles, such as difficulties establishing standardized manufacturing processes with strong quality controls and effective management. Therefore, if developing countries produce chairs using the standard materials used in developed countries, they might be frail.

Focusing on how elementary school children as a user carry, lift, and turn chairs in common class activities can provide alternative strategies for modifying Indonesian elementary school chairs without decreasing their weight. Due to individual differences in age, physique, knowledge, etc., children use various carrying methods to complete the same tasks. Previous studies have focused on the effects of carrying methods on anterior load carrying capability. It was found that carrying a load at hand height had better carrying capacity than carrying at elbow height [47, 54]. As such, examining popular carrying methods could indicate that it might be easier for children to perform tasks using their preferred methods.

Thus, the second factor (after weight) in investigating Indonesian elementary school chairs is the parts of chairs most popularly used for grasping. Some parts of these chairs are too thick for children to grasp. Moreover, there are sharp corners, making them unsafe. The shapes of these chairs suggest they were not designed to be easily moved. Without improvements, such poorly designed chairs can create hazardous situations and possibly result in injuries. Thus, in redesigning chairs without decreasing their weight for improved ease of transport, parts popularly used for grasping should be suitably shaped to facilitate effective methods of lifting, carrying, and turning.

To obtain useful basic data for redesigning elementary school chairs to be easily lifted and turned by young children, this study investigated the methods children aged 6-9 used to carry chairs and to lift and turn them onto desks. First, the chair carrying methods, including direction and sequence, were examined. Second, which parts of chairs were most commonly grasped while performing tasks, were investigated.

2. Materials and methods

2.1. Participants

The participants in the present study were the same as the participants that involved in Chapter 2. They were a total of 42 children (aged 6-9), including 17 Indonesians (6 boys and 11 girls) and 25 Japanese (12 boys and 13 girls).

2.2. Experimental instruments

2.2.1. Chairs

In order to compare the effect of three dimensions and weight conditions on the carrying, lifting and turning a chair methods, the whole experiment of this chapter used the same chairs as the Chapter 2.

2.2.2. Desks

In this chapter, two desks with two conditions were only used in the experiment of lifting and turning a chair. Those were same desks that were used in Chapter 2.

2.3. Experimental tasks, conditions, and procedures

Two tasks which were carrying a chair and turning and lifting a chair onto a desk, were performed in the appropriate experimental space. Those tasks used the same conditions and procedures as Chapter 2.

2.4. Measurements

Each participant’s movement was recorded by a digital video camera (Panasonic, HC-V 300 M, Japan) at 30 frames per second. To record tasks in detail, the camera was operated freely by hand (i.e., not mounted, as on a tripod), following participants’ movements step by step, such as their methods for carrying chairs and their grasping positions on the chairs.

2.4.1. Grasping part of the chair

Before conducting the experiments, 18 parts of the chairs were coded A-R as the possible points that might be grasped by participants (Fig.3. 1, Table 3.1).

Indonesian Chair **Japanese Chair**

Fig. 3.1. The codes of the chairs part

Table 3.1. Codes of the chair parts

Code	Part of the chair
A	Top of the back
B	Bottom of the back
C	Right of the back
D	Left of the back
E	Right of the chair's back stand
F	Left of the chair's back stand
G	Back of the seat
H	Right of the seat
I	Left of the seat
J	Front of the seat
K	Right-back of the chair's foot
L	Left-back of the chair's foot
M	Right-front of the chair's foot
N	Left-front of the chair's foot
O	Additional construction on the chair's back
P	Right of additional construction on the chair's foot
Q	Left of additional construction on the chair's foot
R	Front of additional construction on the chair's foot

2.4.2. The criteria of success in lifting and turning a chair

The success criteria of the lifting and turning a chair were almost exactly the same as the Chapter 2.

2.5. Statistical analysis

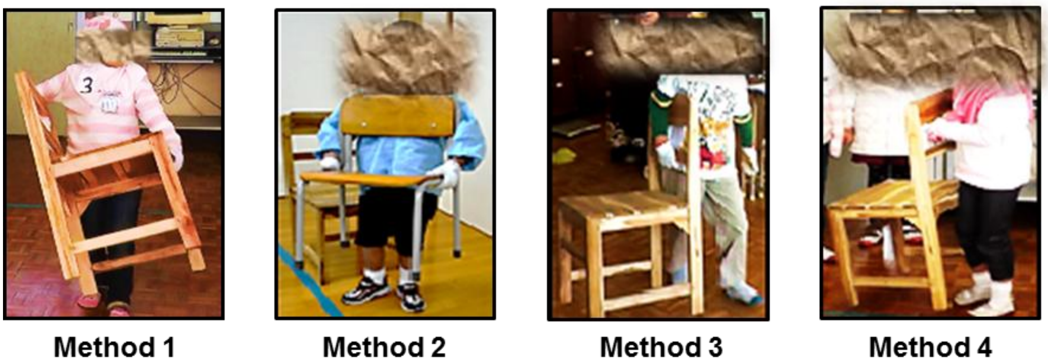
The SPSS statistical package (IBM SPSS version 21.0 for Windows, Chicago, USA) was used to analyze the data. The exact chi-square test [68-69] was calculated to analyze the effects of chair type on the success rate.

3. Results

3.1. Carrying a chair

The methods for carrying chairs were categorized based on the chair's direction, its orientation, and how many hands the child used. Fig. 3.2 shows the four main carrying methods. Those carrying methods were:

- Carrying method 1: The chair was carried in front of the child's body with two hands on two parts of the chair, and the chair's orientation was lateral.
- Carrying method 2: The chair was carried in front of the child's body with two hands on two parts of the chair, and the chair's direction was either forward or backward.
- Carrying method 3: The chair was carried at the side of the child's body with one hand in one position.
- Carrying method 4: The chair was carried at the side or in front of the child's body with two hands on one part of the chair.



-

Fig. 3.2. Four methods of chair carrying

Fig. 3.3 shows the percentages of carrying methods used by participants for every chair type in the experiment. Method 1 was used the most (75%), followed by Method 2 (16%). Methods 3 (5%) and 4 (4%) were rarely used. The exact chi-square test indicated no significant effect of chair type on carrying method.

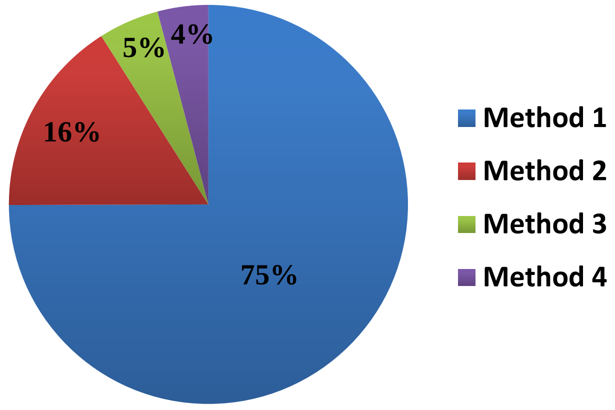


Fig. 3.3. Percentages of the carrying methods used for every chair-types

The participants employed various grasping patterns, using one or two hands to grasp certain parts of the chairs. Table 3.2 shows nine grasping patterns used by participants: AJ, BJ, DJ, GJ, HI, OO, BB, O, and B. AJ, for example, means the chair was grasped by two hands with the right or left hand on Part A and the other hand on Part J. In Patterns B and O, the chair was grasped using only the left or right hand.

Each carrying method had specific grasping patterns. For example, Method 1 showed Patterns AJ, BJ, DJ, and GJ; Method 2 showed Patterns HI and OO; Method 3 showed Patterns BB and O; and Method 4 showed Patterns B and OO. Pattern OO, observed in Methods 2 and 4, was a special case. Table 3.3 shows the percentages of grasping patterns used for each chair type. Parts J, A, and B showed a higher frequency than the other parts. Meanwhile, Parts C, E, F, K, L, M, and N were not used by any participants.

Table 3. 2. Frequency of each carrying method at each grasping pattern by chair-type.

Method of carrying the chair	Grasping pattern	Frequency for each chair type		
		Chair A	Chair B	Chair C
1	AJ	21	19	3
	BJ	9	10	16
	DJ	0	0	7
	GJ	2	1	4
2	HI	6	7	6
	OO	0	0	1
3	BB	2	2	1
	O	0	0	1
4	B	1	2	0
	OO	0	0	2

Table 3. 3. Frequency of each part of all chair types by childern's grasp

Part code	Frequency (percentage)	Part code	Frequency (percentage)	Part code	Frequency (percentage)
A	43 (18%)	F	-	K	-
B	45 (19%)	G	7 (3%)	L	-
C	-	H	19 (8%)	M	-
D	7 (3%)	I	19 (8%)	N	-
E	-	J	92 (38%)	O	7 (3%)

3.2. Lifting and turning a chair onto desk

3.2.1. Popular grasping patterns

Participants lifted and turned chairs onto desks using various grasping patterns on different parts of the chairs. They completed the task in steps using different grasping patterns. Grasping patterns were categorized according to the child's first step in grasping the chair. Forty first-step grasping patterns were identified for all chairs and desks. Participants primarily used seven grasping patterns, with AJ/JA and BJ/JB as the most popular. The 33 other patterns were less popular. Table 3.4 shows the distribution of the popular grasping patterns.

Table 3. 4. Frequency of each popular first-step grasping pattern by chair-type

Grasping pattern	Frequency for three chairs on two desks					
	Standard desk			Tall desk		
	Chair A	Chair B	Chair C	Chair A	Chair B	Chair C
AJ/JA	13	13	4	16	12	5
BJ/JB	7	6	13	5	7	3
MK/KM	1	2	0	5	4	2
KL/LK	3	2	2	1	4	2
NA/AN	3	1	1	2	4	1
JG/GJ	3	3	2	1	2	1
EF/FE	1	2	2	2	2	2
Un-popular	11	13	18	10	7	26

3.2.2. Popular grasping patterns and success rates

Fig. 3.4 shows the success rates for lifting and turning three types of chairs onto standard and tall desks. For both desk types, the popular grasping patterns had higher success rates than the unpopular ones with each chair type (Fig. 3.4). The success rates for both popular and unpopular grasping patterns decreased gradually from chairs A to C with both desks. The highest success rate (90%) was achieved with chair A and the standard desk. The lowest success rates, or unpopular grasping patterns, occurred with chair C with the tall (12%) and standard desks (20%) (Fig. 3.4).

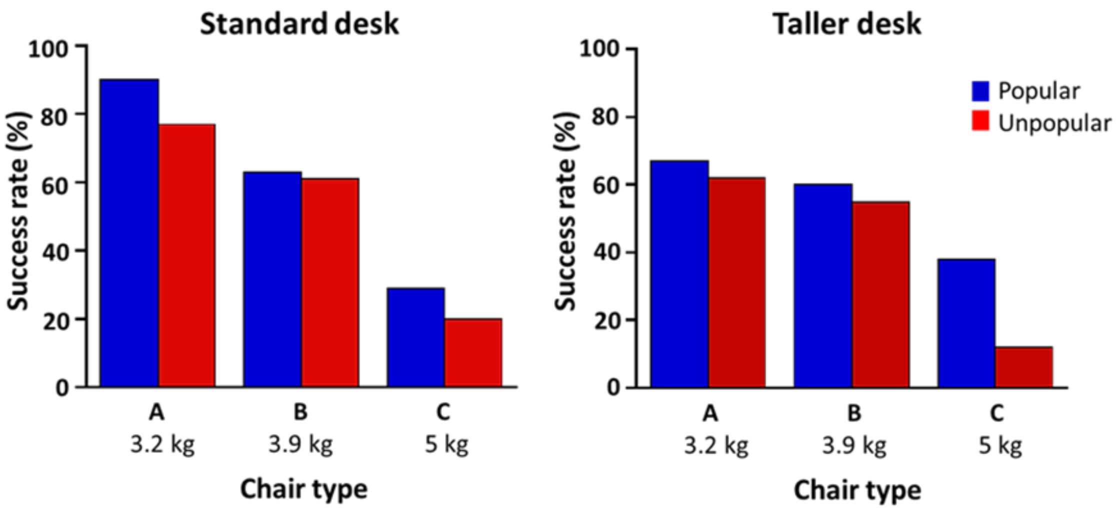


Fig. 3.4. Success rates of popular and unpopular grasping patterns for lifting and turning the three types of chairs on standard and taller desks.

Fig. 3.5 shows the success rates for popular and unpopular grasping patterns for all chair types with both standard and tall desks. The exact chi-square test found that the popular patterns had significantly higher success rates than the unpopular patterns with tall desks (60% and 40%, respectively) but not with standard desks (60% and 50%, respectively).

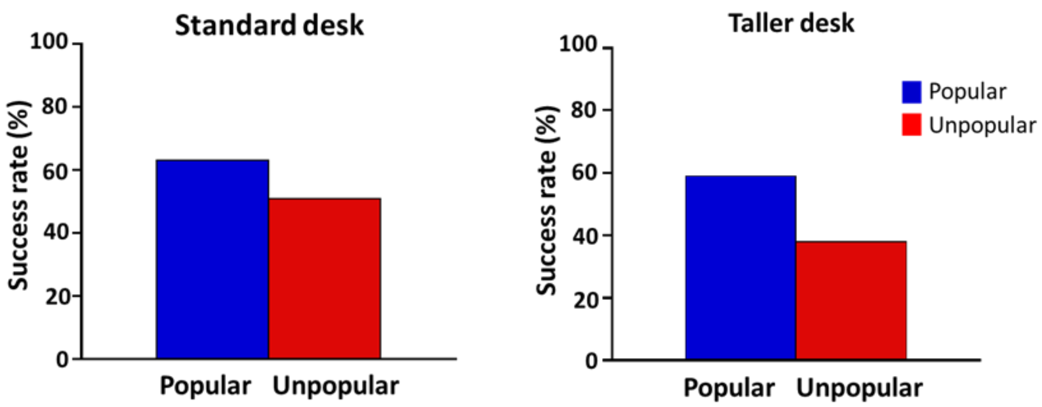


Fig. 3. 5. Success rates for popular and unpopular grasping patterns in lifting and turning the three types of chairs on standard and taller desks

The popular first-step grasping patterns were followed by the second-step patterns, which were NL/LN and MK/KM. Since NL/LN and MK/KM are the same (left and right of the chair's feet), they were categorized into the same group (Table 3.5).

Table 3.5. Frequency of each popular second-step grasping pattern following the first popular pattern by chair type

Grasping pattern	Frequency for three chairs on two desks					
	Standard desk			Taller desk		
	Chair A	Chair B	Chair C	Chair A	Chair B	Chair C
NL/LN, KM/MK	5	6	4	4	6	2
NF	2	2	1	0	1	1
KA	2	0	0	4	0	0
JF	0	1	1	1	1	2
Others	9	9	8	11	11	2
Total	18	18	14	20	19	7

4. Discussion

4.1. Carrying a chair

This study considered how children carry chairs to redesign them for easier transport. Carrying Method 1 (Fig. 3.2), in which the chair was carried in a lateral orientation in front of the child's body with two hands on two parts of the chair, was the most popular. Understanding how humans use a product is an important factor in product development [79-82]. The preferred carrying method in this study is supported by previous research showing that a user's pleasurable feelings in choosing a product or tool correlate to psychological rather than physical or usability factors [82]. Furthermore, in the material-handling field, Kuijt-Evers et al. [83] found that an object's appearance affected comfort and preference during handling. In the present study, the shape (appearance) of the chair led children to use carrying Method 1. This was because the position of the hands on the chair tended to balance and stabilize the direction of the chair mass so that it seemed easy and comfortable. Future research should investigate whether Method 1 is indeed the easiest and safest way for children to carry chairs. This study showed that chair-carrying methods involved the child's preference for grasping certain parts of the chair. The most popular grasping patterns in Method 1 were AJ and BJ (Table 3.2)—that is, Parts A and B on the top and bottom of the chair's back and Part J on the front of the seat (Tables 3.1). The Indonesian chair's features were too large for the anthropometry of children aged 6-9 [38-39]. Specifically, the distance between Parts A and B for the right hand and Part J for the left was too large. In addition, its heavy weight [Chapter 2] and sharp shape could increase the difficulty of carrying it with a balanced posture and potentially cause injury. Therefore, to improve the ease of transporting Indonesian elementary school chairs without decreasing their weight, the parts children prefer to grasp should be considered.

4.2. Lifting and turning a chair

The results for lifting and turning chairs onto desks also provide guidelines for redesigning chairs based on grasping patterns. The main considerations are the

AJ/JA and BJ/JB patterns, which were used most often in the first step for each type of chair and desk (Table 3.3; Fig. 3.6). Furthermore, AJ/JA and BJ/JB had higher success rates than the less popular grasping patterns for each type of chair and desk (Fig. 3.4, Fig. 3.5). Thus, AJ/JA and BJ/JB are the ideal grasping patterns for children to easily lift and turn both Indonesian and Japanese chairs.

The secondary considerations are the NL/LN and MN/NM patterns, which were used most often in the second step following the most popular grasping patterns in the first step (Fig. 3.6). Further, NL/LN is equivalent to MK/KM, and MN/NM is equivalent to KL/LK. Therefore, Patterns MK/KM, MN/NM, and KL/LK should be considered secondarily after AJ/JA and BJ/JB to improve the ease of lifting and turning chairs.

Grasping pattern AJ at 1st step

Grasping pattern MN at 2nd step

Fig. 3.6. Popular grasping patterns at the first and second steps

The popular patterns (AJ/JA, BJ/JB) nevertheless had low success rates with chair C and both desks (Fig. 3.4), indicating that lifting and turning the Indonesian chair was difficult. Meanwhile, the popular patterns' high success rates with chair A showed that Japanese chairs could be easily lifted and turned. In addition, the exact chi-square test found that the popular patterns' success rates were significantly higher than the unpopular ones only with the tall Indonesian desk. Therefore, grasping patterns must be considered in redesigning Indonesian chairs to make the task of lifting and turning chairs onto tall Indonesian desks easier.

The results for both tasks (carrying and lifting/turning chairs) showed that Parts A, B, and J were used most by children. Those parts were designed more safely on the Japanese chair than the Indonesian chair. The rounded corners and proper sizes of the Japanese chair parts make it easy for children to grasp and carry the chairs. However, those parts are dangerous on Indonesian chairs, making them difficult for children to carry, lift, and turn. The parts are large, there is no convenient place for children to grasp them, and the sharp corners could cause injuries. Moreover, the chair's dimensions are unsuitable for children, especially young children [38-39]. The awkward shapes, weights, and dimensions could cause a younger child to drop the chair. Therefore, considering grasping patterns for redesigning chairs promotes safety in addition to easy lifting.

4.3. Implications, limitation and future research priorities

To my knowledge, using grasping patterns as a criterion for designing elementary school chairs for easy lifting and turning is new in this research area. These findings could be very useful for redesigning and modifying Indonesian elementary school chairs without decreasing their weight. It would be interesting for future investigations to evaluate the effectiveness of such modified Indonesian elementary school chairs.

4.4. Conclusions

It can be concluded from the present study that investigation in this area should consider two factors: the main methods of carrying chairs and the most popular grasping patterns for carrying, lifting, and turning them. These are necessary for designing elementary school chairs for easy carrying and moving—especially the heavy chairs that are found in Indonesian elementary schools.

Chapter 4

The effectiveness of the proper shape and holding positions of the elementary school chair to encourage the student transporting a chair easily

1. Introduction

Alternative strategies to improve ease of transport of chairs in Indonesian elementary schools without decreasing the weight have been proposed in Chapter 3. One of the recommendations is the modification of the parts that are usually grasped when children carry, lift, and turn the chair. The modification should also take into account that some of the parts are too thick for children's grip and the chair's corners are too sharp. To minimize the burden of carrying the load and to provide comfortable handling, previous studies recommended that the load should have handles [84], that sharp corners and edges should be eliminated [54], and that the size or diameter should fit the user's grip [85, 86]. Accordingly, as the carrying handles, the chair parts should be modified with the proper shapes for the children's grip such as an appropriate size and round corner.

Furthermore, the popular holding position, as shown in Chapter 3, indicates two possible positions of the children's right hand (in Parts A and B) (Fig. 4.1). Previous studies indicated that the muscle activities of the upper limb significantly affect the upper limb position during hand activities [55-56, 58]. In an electromyographic (EMG) study of scapular plane abduction with varied loads in hand, Yasojima et al. [56] and Alpert et al. [58] have found that rotator cuff and deltoid muscle activities were influenced by increasing loads and angles of shoulder abduction. In a work that needs precision of hand position combined with carrying of load, Singholm et al. [55] have examined the effect of arm position while having a load in hand, and they recommended that the arm should be close to the body during the work. To improve ease of chair transport, proper upper limb position in carrying, lifting, and turning a chair is needed.

Fig. 4.1. Main method (left) and popular holding position with grasping pattern when carrying a chair (right). The red circles (Parts A, B, and J) indicate the parts of the chair that are usually grasped by children.

Thus, carrying, lifting, and turning of elementary school chairs can be made easier by modifying the shape of the chair based on proper holding position. The aims of the present study were to evaluate the effectiveness of shape modification of chairs in Indonesian elementary schools and to provide the proper holding position when carrying a chair and lifting and turning it onto a desk for children aged 6-8 years. After modifying the chair based on the ideas in Chapter 3, this study examined their effectiveness by comparing original (Chair-OR) and modified chairs (Chair-MD) using three measurements, namely task time, electromyogram (EMG) while carrying a chair, and success rates for lifting and turning a chair.

2. Materials and methods

2.1. Participants

Participants in this study included 14 healthy, right-handed Indonesian (n = 8) and Japanese (n = 6) children (7 boys and 7 girls), aged 6, 7, and 8 years, which correspond to the first, second, and third grades of elementary school. Participant data were as follows (mean ± standard deviation): age, 6.7 ± 0.8 years; height, 119.3 ± 23.1 cm; weight, 21.9 ± 3.1 kg; grip strength, 7.8 ± 1.6 kgf; hand length (wrist to middle finger), 12.9 ± 4.0 cm; grip inside diameter (diameter from the thumb to the middle finger), 28.0 ± 3.0 mm. The Ethics Committee of the Faculty of Design, Kyushu University, Japan, approved this study (approval number: 125).

2.2. Experimental instruments

Representative furniture from Indonesian and Japanese public elementary schools were used as the main equipment in this experiment, including one Indonesian chair, two Japanese chairs, and one Japanese desk.

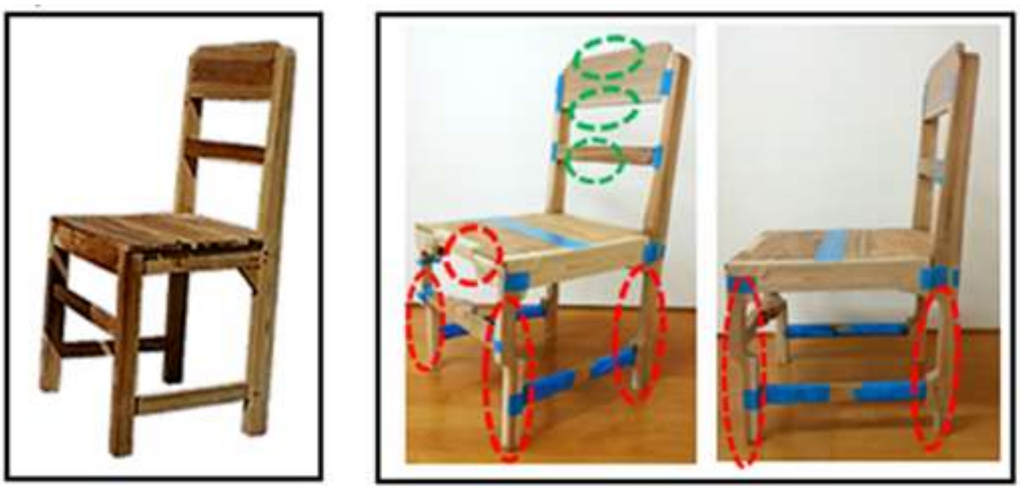
2.2.1. Chairs

Two chairs, Chair-OR and Chair-MD, were examined in this experiment to evaluate the effectiveness of chair modification. Chair-OR was the same chair in Chapters 2 and 3, which is the typical chair used in most public elementary schools in Indonesia (dimension, 400 x 400 x 420 mm, width x depth x seat height; weight, 5.0 kg) [38, 39, 43]. The weight (5 kg) was the lowest in the range of elementary school chairs based on a pilot study of chair weight in 11 public

Indonesian elementary schools [39]. The seat height of the chair was the usual height adopted in Indonesian elementary schools [38-39, 43].

Chair-MD was a Chair-OR adjusted by 1) cutting its holding part and curving off its sharp corners based on the popular grasping pattern in Chapter 3. Fig. 4.2 displays the modified parts of the chair, which included the modification of the front seat and feet based on the size of the children's grip and rounded edges (Fig. 4.2, red circles), and 2) curving the edge of the main and middle backrests (Fig. 4.2, green circles).

The weight of Chair-OR was maintained in Chair-MD, despite the removed parts, by attaching an additional weight that is equal to the lost weight to a hidden part of Chair-MD.



Original Chair (Chair-OR) **Modified Chair (Chair-MD)**

Fig. 4.2. Details of the modified elementary school chair. Red circles, shape became smaller and curvy; green circles, shape became curvy.

2.2.2. Desks

Fig. 4.3 shows the Japanese elementary school desk used in the present study. The height of the desk was 580 mm. This height was appropriate for the participants in this experiment (age, 6-8 years; height, 131-144 cm) and meets ISO 5970 [20].

Fig. 4.3. The Japanese desk height (desk height: 580 mm)

2.3. Experimental conditions

The participants in the present study performed the tasks of carrying the two chair types (Chair-OR and Chair-MD) and lifting and turning a chair onto a desk using two holding positions, which were higher holding position (HHP) and lower holding position (LHP). The holding positions were derived from two popular holding positions in Chapter 3, indicating two popular grasping patterns, which are AJ and BJ (in AJ, the right hand grasps Part A and the left hand grasp Part J, and in BJ, the right hand grasps Part B and the left hand grasps Part J).

However, Chapter 3 indicated that the weight and dimension of elementary school chairs in Indonesia are too heavy and oversized for younger children. Consequently, the position of the right hand in Part A, which is the part usually grasped, is critical. From the biomechanical point of view, grasping Part A is riskier for children when carrying a heavy and oversized chair because they would need to abduct their shoulder over 90 degree to grasp that part, which is not recommended [55]. Moreover, the down-facing direction of the hand while grasping the heavy chair can lead to the loosening of grasps, and thus dropping of the chair. To eliminate the constraints, this study discarded Part A and recommended that Part B should be grasped instead. Alternatively, Part O was used as an additional part to grasp. The children can grasp Part O in the same direction as Part B, where in the hand is facing up. In Chapter 3, the children grasped Part O as well when carrying a chair.

In summary, the present study used two holding positions modified from the holding position in Chapter 3. The first was HHP of the right upper limb, which used the Grasping pattern BJ, wherein the right and left hands grasped Part B and J, respectively, and has a higher position in the right upper limb. The second was LHP, which used the Grasping pattern OJ, where in the right and left hands grasped Parts O and J, respectively, and has a lower position in the right upper limb.

Furthermore, according to Chapter 3, in this study, lifting and turning a chair involve two steps. In the first step, while lifting the chair, HHP was adopted, which was the same position used in carrying the chair. In the second step, when turning the chair onto the desk, the right or left hand grasps the chair feet (Parts K, L, M, or N; Fig. 4.4).

Fig. 4.4. The method of carrying a chair using two holding positions of right upper limb: (1) higher holding position (left): shoulder abducted 60-90° and neutrally rotated, elbow flexed at 45-90°; (2) lower holding position (right): shoulder abducted 30-60° and neutrally rotated, elbow flexed at 45-60°.

2.4. Experimental procedures

The experiment was done for 6 days in August to September 2014 in a large and flat experimental room of the Faculty of Design, Kyushu University, under comfortable temperature. To compare the differences of Chair-OR and Chair-MD, the same tasks as in Chapter 3 were performed by the participants: 1) carrying a chair and 2) turning and lifting a chair onto a desk.

For each task, all participants practiced before the actual experiment. A brief instruction was given to help them perform the protocol completely. To prevent injury, they used nonslip shoes and gloves. An adult assistant accompanied them for safety and tells when to stop if in a dangerous situation and if the condition looked impossible to continue. After finishing each task, participants were asked about conditions such as pain, fatigue, lack of motivation, etc. to anticipate task difficulty.

2.4.1. Task 1: Carrying a chair

Participants brought the Chair-OR and Chair-MD from the start to the finish line (distance, 5 m) using the recommended carrying method (Chapter 3), which was carrying the chair in front of the child's body with two hands on two parts of the chair and with the chair oriented laterally (Fig. 4.4). Then, according to the above experimental conditions, the participants carrying Chair-OR and Chair-MD used two holding positions in random order (Fig. 4.4). The other technical procedures in this task were the same as the procedures in Chapter 2.

2.4.2. Task 2: Lifting and turning a chair upside down

The present study adopted the recommended carrying method (Chapter 3), which was the carrying the chair in front of the child's body with two hands on two parts of the chair and the chair oriented laterally, using two popular holding positions (HHP and LHP) (Chapter 3). The holding positions and grasping patterns according to the above explanation about the experimental condition. In this task, participants used two steps to turn and lift the Chair-OR and Chair-MD upside down in a random order. The other technical procedures were the same those in lifting and turning a chair in Chapter 2.

2.5. Measurements

2.5.1. Task carrying a chair

2.5.1.1. Task time

In the task of carrying a chair, three methods were used to measure task time. First, a manual stopwatch measured the real time of the task. Second, the task time was measured by frame-by-frame playback of movies that were recorded by a digital video camera (HC-V 300 M; Panasonic, Tokyo, Japan). Third, to monitor the chair movement, a pressure sensor (S120, PH-463; diameter, 12 mm, thickness, 0.5 mm; Nihon Kohden, Tokyo, Japan) was attached to the bottom of one chair leg. The output of the sensor was monitored by a computer. Task period was defined as the time point when one chair leg bottom was raised off the floor to the time point when the chair touched the floor. The combination of the three methods was used to ensure accurate time measurement.

2.5.1.2. Electromyogram

In the task of carrying chairs, surface EMG was measured using a multichannel telemetry system (WEB-7000; Nihon Kohden, Tokyo, Japan). EMG electrodes (ZB-150H; Nihon Kohden, Tokyo, Japan) were attached to six muscles of the right and left arms, which were middle fibers of the deltoid (DMF), biceps brachii (BB), and finger flexors (FF) (Fig. 4.5). EMG data used a sampling frequency of 1 kHz with low-cut filtering at 15 Hz. The WEB 1000/7000 application program (QP-700H; Nihon Kohden, Tokyo, Japan) recorded the EMG data synchronized with the pressure sensor.

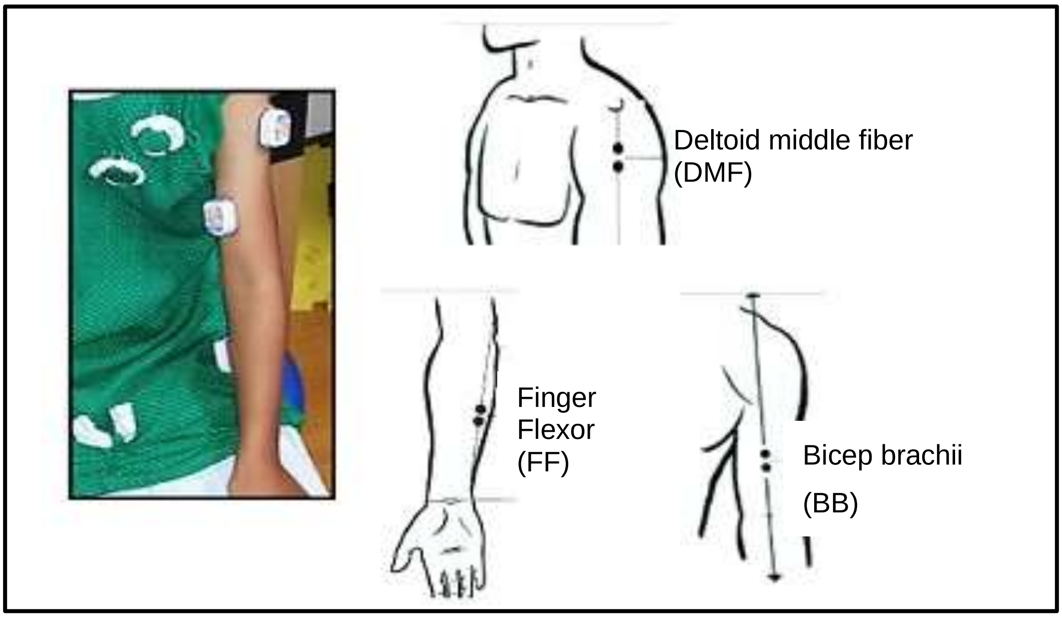


Fig. 4.5. Electrodes attachment of EMG on three muscles: Deltoid Middle Fiber (DMF), Bicep brachii (BB), Finger flexor (FF) [88]

After the skin was cleaned with alcohol, electrodes were placed on the skin surface of the selected muscles. For the DMF, the electrode was placed on the lateral aspect of the upper arm, below the acromion [89] approximately a quarter of the distance from the acromion to the elbow, on the greatest bulge of the muscle [88]. For the biceps brachii, the electrode was placed on the center of the muscle mass [89], which was one third from the cubital fossa and between the medial acromion and the cubital fossa [90]. For the finger flexor, the electrode was placed on the ventral aspect of the arm and over the belly of the muscle in the direction of the muscle fiber [89]. It was centered around the midpoint on the line joining the medial epicondyle to the styloid process of the ulna [88].

2.5.1.3. Maximum voluntary contraction recording

Before the task, a test of maximum voluntary contraction (MVC) was conducted for the normalization of EMG activity. Participants performed an MVC against static resistance of each muscle for 3 seconds. The MVC of the six muscles was according to previous studies and handbook test [100-102]. After the completion of the MVC test, the EMG measurement of task was done.

2.5.1.4. Data analysis of EMG

The signals of EMG were rectified and averaged across the data collection period, which was from the start to the end of the task. For each participant, the mean EMG data of each muscle were normalized relative to the mean MVC EMG data, namely the percentage of EMG (% EMG).

2.5.2. Task lifting and turning a chair

In the task involving lifting and turning a chair onto the desk, the criteria of success and unsuccessful completing the task was same as the criteria that was used in the lifting and turning a chair of Chapter 2.

2.6. Statistical analysis

IBM SPSS version 21.0 for Windows (2012; IBM, Chicago, IL, USA) was used to perform statistical analyses. A repeated measures two-way analysis of variance (ANOVA) examined the effects of two types of the chairs and two holding positions on task time and EMG activities. The success rates between chair types and between carrying patterns for the lifting and turning task were compared using Fisher's exact test [68, 69]. The level of significance was set at $p < 0.05$.

3. Results

3.1. Carrying a chair

3.1.1. Task time

All participants (n = 14) completed four tasks, carrying Chair-OR using HHP (Chair-OR_HHP), carrying Chair-OR using LHP (Chair-OR_LHP), carrying Chair-MD using HHP (Chair-MD_HHP), and carrying Chair-MD using LHP (Chair-MD_LHP) (task time, mean ± SD: Chair-OR_HHP, 7.9 ± 1.3 sec; Chair-OR_LHP, 7.8 ± 1.0 sec; Chair-MD_HHP, 7.5 ± 1.3 sec; Chair-MD_LHP, 7.1 ± 1.1 sec). Repeated measures two-way ANOVA showed significant effects of chair types and holding positions ($p < 0.05$). Fig. 4.5 6 displays the task time comparison of carrying a chair. The task time of Chair-MD was significantly shorter than that of Chair-OR, and the task time of LHP was significantly shorter than that of HHP ($p < 0.05$).

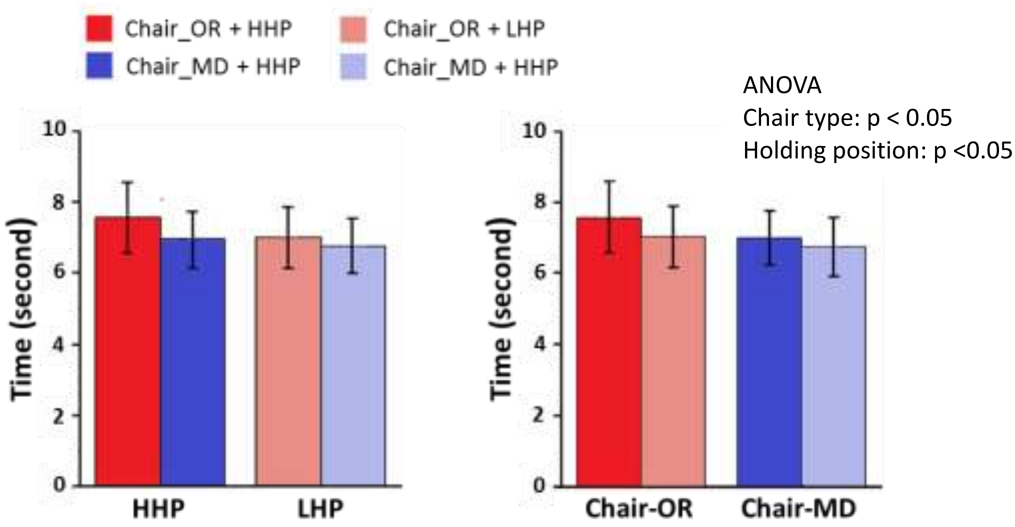


Fig. 4.6. Task time comparison of carrying a chair:
The effects of (left) two chair types (Chair-OR and Chair-MD) and (right) two holding positions (HHP and LHP) on task time.

3.1.2. The effect of holding position on task time and EMG

Table 4.1 displays the result of the % EMG of each muscle when carrying a chair. ANOVA showed that only the right DMF has a significant effect on % EMG (Table 4.2). Fig. 4.7 displays the % EMG of the DMF when comparing both holding positions. The % EMG of the DMF when using Chair-MD was significantly lower than that when using Chair-OR ($p < 0.05$). In both chair types, the % EMG of the DMF using LHP was significantly lower than that when using HHP ($p < 0.05$).

Table 4.1. %EMG in the carrying a chair using 2 chair types and 2 holding positions (Mean ± SD)

Side	Muscle	N	Chair-OR		Chair-MD	
			HHP (M ± SD)	LHP (M ± SD)	HHP (M ± SD)	LHP (M ± SD)
Right	DMF	7	41.3 ± 24.1	28.0 ± 18.7	34.1 ± 22.8	25.1 ± 19.3
	BB	7	41.3 ± 25.5	55.4 ± 39.8	47.5 ± 28.9	55.7 ± 26.6
	FF	7	71.4 ± 36.3	73.1 ± 34.1	78.8 ± 49.2	79.3 ± 46.1
Left	DMF	6	9.8 ± 6.4	12.5 ± 9.6	11.1 ± 9.4	14.3 ± 11.3
	BB	4	59.4 ± 15.0	52.7 ± 15.6	56.9 ± 11.6	57.4 ± 5.0
	FF	7	44.7 ± 26.4	63.4 ± 42.0	55.2 ± 50.7	60.6 ± 44.5

DMF: deltoid middle fiber; BB: bicep brachi; FF: finger flexor

Table 4.2. Result of repeated measure two way ANOVA of muscle activities in carrying a chair using 2 chair types and 2 holding positions

Effect	Right side			Left side		
	DMF	BB	FF	DMF	BB	FF
Chair type	F = 6.56 P < 0.05	n.s	n.s	n.s	n.s	n.s
Holding position	F = 5.27 P < 0.05	n.s	n.s	n.s	n.s	n.s
Interaction	n.s	n.s	n.s	n.s	n.s	n.s

DMF: deltoid middle fiber; BB: bicep brachii; FF: finger flexor
n.s: not significance

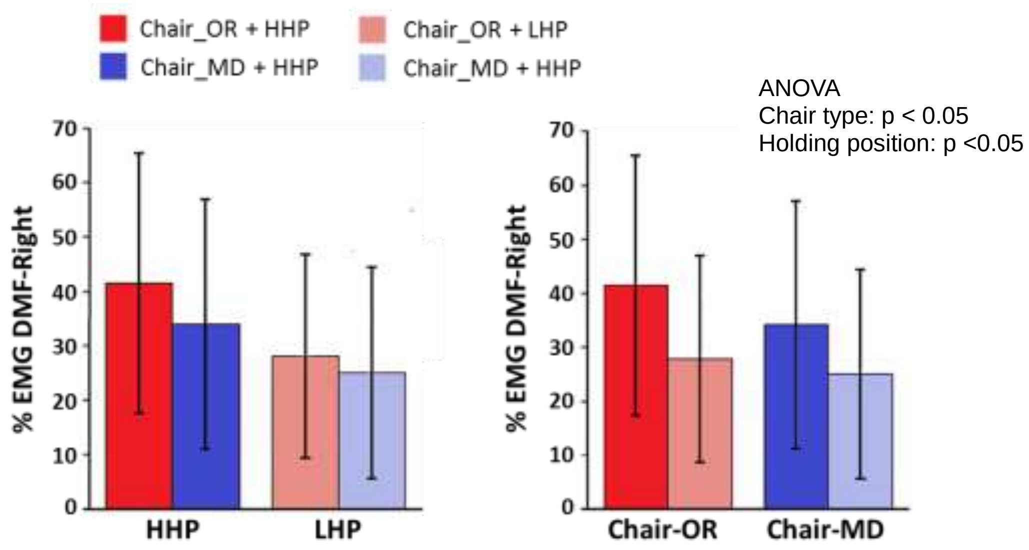


Fig. 4.7 Effects of chair types and holding positions on the % EMG of the right deltoid middle fiber (DMF-Right) activity when carrying a chair.

3.2. Lifting and turning a chair

Table 4.3 shows the success rate (percentage) of the participants in lifting and turning a chair in all conditions. Participants ages 6 and 7 years did not succeed in any chair type or holding positions. In contrast, participants almost 8 years old could lift and turn the chair successfully (success rate, 67%). In the Fisher's exact test lifting and turning by all participants in all conditions (between Chair-OR and Chair-MD or between HHP and LLP) did not reveal any significant difference in success rate ($p = 1.00$).

Table 4.3. The success number of lifting and turning a chair

Age (years)	N	Chair-OR (N)		Chair-MD (N)	
		HHP	LHP	HHP	LHP
6	6	0	0	0	0
7	5	0	0	0	0
8	3	2	2	2	2
Total	14	2	2	2	2

4. Discussion

4.1. Task: carrying a chair

4.1.1. Effect of chair modification on task time and EMG

To improve the carrying of a chair without decreasing its weight, Chapter 3 recommended the modification of the parts that are grasped by children. First, a curved edge was adopted on Parts B and O, which are the bottom of the main backrest and the middle backrest of the chair, respectively. Second, a curved edge and a smaller size were adopted for Part J (bottom of the front seat). Curving the sharp edge of the Chair-OR was done to improve comfort and safer handling of the chair by children. Furthermore, the diameter of Chair-MD was based on the inside grip diameter of the children who participated in this research (average, ≤25 mm). Even though children could not fully grasp Part J due to the direct mounting on the chair's seat, the decrease in size was expected to be comfortable when the chair is carried.

A positive result was achieved in the present study, that is, the task time of carrying Chair-MD was statistically significantly faster than that of Chair-OR. It indicates that the modifications made the chair more satisfactory for children and carrying the chair became easier for them. The curved shape of Chair-MD in this study was close to the cylindrical shape preferred during carrying activity, as recommended by Mital and Okolie [54]. Drury [53] also recommended the elimination of sharp corners, edges, ridges, and finger grooves to reduce excessive loading. Accordingly, even though the weight of Chair-MD was the same as that of Chair-OR, the curve edge encouraged the children to grasp the chair's part easily and comfortably and to continue walking and carrying the chair with a better balance posture, which indicates that the task time could be shortened by shape modification.

The result showed that modifying Parts B and O significantly decreased the % EMG of the right DMF. The lower muscle activities indicate low burden on muscle or comfortable handling [55], whereas, according to previous studies [55, 56, 57, 94], the low burden of DMF was strongly affected by the angle of shoulder abduction. Furthermore, the results of a previous study [55] showed that increasing the load in the hand could increase the activity of the deltoid. This can be attributed to the increase in the torque of the glenohumeral joint [95] owing to the increasing load in the hand, which acts as a stabilizer of the complex shoulder joint [55]. This can induce shoulder abduction and increase DMF activity. Accordingly, in the present study, decreasing right DMF activity by curving Parts

B and O leads to the reduction of the excessive weight of the chair as a compensation for the decrease in the angle of abduction due to decreasing torque of glenohumeral joint. Thus, it can be derived from this study that due to a comfortable handling brought about by the curved edge, the excessive weight could be eliminated.

In addition, modifying the shape significantly influenced the % EMG of the right DMF, but not that of the left side. It may be caused by the position of the right hand on the chair, which was higher than the left hand, in the carrying activities. Consequently, participants tend to abduct the right shoulder rather than the left shoulder, and the left hand was more relaxed.

4.1.2. Effect of holding position on task time and EMG

The result of the present study showed that the task time of carrying a chair using LHP was significantly faster than using HHP, i.e., the time for completing the task became faster owing to high upper limb position. It can be explained by the finding that the higher position of the children's upper limb on a chair indicated the higher elevation of arm abduction, which led to higher muscle activities and higher force of the muscle [54, 95]. Consequently, with a higher burden of carrying a load, walking effort became higher as well and task time became longer because of the need to maintain stability. In addition, early studies reported that a significant interaction between speed and load height position when carrying a heavier load [96] and a higher load position on the body led to a longer time in carrying a load [47, 54]. Thus, the decreasing the burden of the load in carrying a chair using the lower position of upper limb would shorten task time.

The effect of the right LHP, where in the right hand is grasping Part O, is same as the effect of shape modification, which significantly decreased the % EMG Right DMF. Even though increasing the muscle activity in the shoulder was influenced by the increased weight in the hand [55], the lower position of the upper limb with the same load in hand significantly decreased the DMF muscles as a lifter muscle [55, 56]. Thus, decreasing the burden of this muscle is indicated [55]. Work in the lower upper limb decreases the torque of the glenohumeral joint and leads to the abduction and decrease of its main function, which is due to the rotator cuff muscles acting as stabilizer of the shoulder joint, thus possibly increasing its stabilization with an increasing hand activity [55, 95, 96, 98]. Decreasing the activity of DMF muscles also prevents overloading [55]. In addition, to reduce the risk due to overloading in the shoulder muscles, working with the hand above the shoulder level is not recommended [99, 100]. It can be derived from the present study that it is safer for children to carry a chair by grasping Part O, which is usually placed on the lower shoulder muscle, thus minimizing the excessive weight of the chair.

4.2. Task: Lifting and turning a chair onto a desk

To encourage comfort when grasping a chair and to improve the ease of transport of the chair, two strategies were adopted in the task of lifting and turning elementary school chairs: first was modifying the part of the chair usually grasped to a curved rectangle edge [53, 54] and the second was adapting the diameter to the average grasp of the children [85, 86]. According to the National Institute of Advanced Industrial Science and Technology [101], the ratio of mean adult hand length to its grip inside diameter (182.6–44.4 mm) is 4.11. Using this ratio, the grip inside diameter of children with mean age of 7 years and mean hand length of 126 mm [102] is 30.7 mm. The diameters of Parts K, L, M, and N, which were adapted to the grip inside diameter of the participants (≤25 mm), were smaller than the above calculations. Second, a LHP of the first step was adopted to decrease the burden of the heavy chair [55]. However, the children were unsuccessful in completing the task despite adopting proper shape and holding positions, thus indicating that those strategies did not encourage the children in lifting and turning a chair.

The heavy weight might be the main reason why the children were discouraged from completing the task. It can be explained by the fact that when turning a chair, the child's hands grasped Parts K, L, M, or N (the feet of the chair), which were upside down, and then lift up those feet before putting the chair's seat, which is opposite to the feet, onto the desk. This condition induced a higher angle of abduction in the upper limbs of the children, which would be located above the shoulder level. According to previous studies [55, 56], lifting heavy weight using the higher-angle abduction could significantly increase the burden on the muscle. The torque of the glenohumeral joint would be increased because of work on the higher part of the arms [55, 95, 97, 98]. Moreover, working with the hand above shoulder level is risky because of the excessive load on the shoulder muscles [99,100]. Accordingly, a comfortable grasp and a proper holding position on the chair did not counter the heavy chair weight and its additional muscle burden.

4.3. Limitation and future research priorities

The result of the present study provides alternative solutions in reducing the burden of carrying heavy chairs in children ages 6-8 years without decreasing the weight. However, the participants involved in the present study are very few. The body sway of the children when walking during the completion of the task, for instance, can cause inaccurate measurement and contribute to the noise in the EMG result, which possibly affected the accuracy of the EMG results. Because of these limitations, this study failed to determine the effectiveness of carrying a Chair-MD using the FF and FB muscles in proper holding position. Thus, it is necessary to add more participants and isolate the problems related to EMG measurement.

4.4. Conclusions

Two effective methods adopted include 1) modifying the shape of the popular grasping pattern with a curved rectangle edge and based on the size of children's grasp and 2) carrying a chair in the LHP or below shoulder level, which makes it easier for children to carry chairs.

Chapter 5

General discussion

1. Summary

The objective of this dissertation was to determine the proper weight, shape, and holding position of Indonesian elementary school furniture, and chairs in particular, for easy carrying, lifting, and turning by children aged 6-9 to encourage active learning in the classroom. To achieve this objective, three studies were conducted. First, a study was conducted of the effects of elementary school furniture weight and children's age on the performance of three tasks—carrying a chair, carrying both a chair and a desk, and lifting a chair onto a desk. Second, a study of the methods of transporting and holding a chair was conducted. Third, a study was conducted to evaluate the effectiveness of implementing chair modifications and a holding position based on the second study for heavy Indonesian elementary school chairs without decreasing weight, as recommended in the first study.

The first study (Chapter 2) established weight guidelines for elementary school furniture that were proportional to children's body dimensions at certain ages, for the performance of three carrying tasks. In the carrying-a-chair task, heavy weight significantly increased task time. This was in line with previous findings that heavy loads decreased walking speed [38-40]. Similar findings were shown for the task of lifting and turning a chair, and for the task of carrying a chair and desk together, such that success rates for completing the task significantly decreased for heavier furniture. Decreasing age also decreased success rates for both lifting and turning a chair and carrying a chair and desk together. These indicated that children aged 6-7 should carry a chair with a weight

lower than the lowest weight of the chair (3.2 kg), which was used in this study. Children aged 6 should not lift and turn a chair, and carry a chair and desk together. Three tasks indicated that the heavier Indonesian elementary school chair, which was the focus of the study, would result in decreasing performance with respect to transporting the chair. Therefore, to ease chair transport, it was recommended that the weight of Indonesian school furniture be proportional to children's age ranges.

The second study (Chapter 3) investigated methods of carrying and grasping a chair [14-16, 18] that might provide an alternative solution for redesigning the Indonesian elementary school chair. A focus on user preferences for carrying and grasping might be necessary due to difficulties in decreasing the weight of the Indonesian chair, related to the fact that the redesigned chair will use the same material as the original chair. The most popular method for carrying a chair was in front of the body with the chair in a lateral position. Participants showed a preference for grasping in two particular positions to hold the chair. These positions seemed easy and comfortable for the child's hands, which tended to remain in a balanced position in the direction of the chair mass. For lifting and turning a chair onto a desk, popular grasping patterns were identified based on children successfully using them. Results indicated that success rates for carrying and lifting the Indonesian chair were still low, even using popular grasping patterns, because the distance between the right hand and left hand was too large for children aged 6-9. In addition, the heavy weight, sharp edges, and improper size of the chair lead children to hold it unstably and drop it to the floor. Therefore, considering grasping patterns when redesigning chairs without decreasing weight promotes safety and easy chair transport.

In the third study, an Indonesian elementary school chair was modified, without decreasing the weight, to accommodate a comfortable grasp and ease of transport (Chapter 3). The sharp edge of the popular grasping part was curved and the thickness was reduced based on the hand size of children. The effectiveness of strategies using popular holding positions, such as the lower holding position (LHP) and higher holding position (HHP) for carrying a chair, and lifting and turning onto a desk for children aged 6-8 were examined. The chair modification and LHP significantly reduced task time, and significantly decreased activity in the right deltoid middle fiber (DMF) of children. However, for lifting and turning a chair onto a desk, in contrast to carrying a chair, the heavy weight of the chair discouraged ease of transport, such that success rates for completing the task did not improve.

2. Implications

The findings of this dissertation have implications for future investment and policy decisions to improve the quality of education, especially in Indonesia and other developing countries. The government, as an institution responsible for education, should create a policy requiring that elementary school chair types be easy to transport and designed differently for students in grades 1, 2, and 3 versus those in grades 4, 5, and 6. According to these guidelines for chair weights, manufacturers can reduce the weight of popular grasping parts of chairs. Finally, schools can promote proper methods for holding chairs among school children.

The Ministry of Education, as a representative of the central institution of education in the Indonesian government, has the a guideline for local government or private institution that elementary school chair should be easy to transport by children themselves, and should be divided into two groups, which were for grade 1, 2 and 3 and for group 4, 5, 6 [18, 20-21]. However, guidelines should be evaluated to ensure that school chair dimensions matched to children's body dimensions [38-40] do not lead to excessive chair weight. Importantly, guidelines should be revised in more detail, including revisions to chair dimensions, weight guidelines, and proper holding positions. In order to disseminate policies across Indonesia, their execution should be supervised by adequate systems of government.

3. Limitations

Although our knowledge about load weight, children's carrying and lifting success, and children's holding preferences have been expanded based on this research and this study reports new findings in the ergonomics field, some limitations should be considered. First, participants were young children, and each child had unique habits and different experiences that related to completing the study tasks. Moreover, the children's understanding of how to perform the task varied. Thus, similarity in experiences and understanding by participants might improve the results. Second, this study did not measure subjective factors, such as children's degree of preferences or favored methods of doing tasks. According to research on manual material handling [103], since carrying and lifting a load not only involve physiology, but also psychology, user preferences, such as perceived ease and choice of carrying position, should be measured in addition to objective measurements. However, the development of language and understanding are not the same for all children aged 6-9. Thus, not all children would be able to answer accurately about their preferred method.

4. Future research priorities

In the future, in order to expand practical findings, it is necessary to employ more types of elementary school chairs in investigations, especially more types of chairs from Indonesian and other developing countries. Involving children from other developing countries with varied body dimensions is also needed. Furthermore, in the current study, ease of chair transport was measured through task time and successful task completion, and indicator of children's performance. Thus, our findings might help to eliminate accidents due to difficulties completing the task. Further research on preventing accidents needs to be conducted.

5. Conclusions

This dissertation demonstrates the significant findings that Indonesian elementary school furniture is too heavy and oversized for children at a younger age to complete the tasks of carrying, lifting, and turning. In order to eliminate difficulties in completing tasks without decreasing furniture weight, two effective strategies are recommended. First, the shape of popular grasping parts can be modified to have a curved rectangle edge and be of a proper size. These parts are easy to hold and can be matched to the hand grip size of children. Second, chairs should be moved using the proper holding position, in which the left hand is at the front of the seat, and the right hand is at the back of the chair. Other strategies should be investigated for lifting and turning a chair. The findings of this dissertation will be useful to propose further research for redesigning Indonesian elementary school chairs, to encourage learning activities, which will improve the quality of Indonesian education.

References

1. Bonwell C. C., & Eison, J. A. (1991). *Active learning: Creating excitement in the classroom, 1991 ASHE-ERIC Higher Education Reports*. Washington DC: The George Washington University.
2. Akinoglu, O., & Ozkardas T, R. (2007). The Effects of problem-based active learning in science education on students' academic achievement, attitude and concept learning. *Eurasia Journal of Mathematics, Science & Technology Education* , 3(1), 71–81.
3. Pardjono, Groves, S., & Gough, J. (1999). *Constructing teaching models of student active learning from classroom observation*. Doctoral Thesis, Australia: Deakin University.
4. Stern, D., & Huber, G. L. (1997). Active learning for students and teachers: Reports from eight countries. Frankfurt: Peter Lang.
5. Johnson, L. M. (2006). Elementary school students' learning preferences and the classroom learning environment: Implications for educational practice and policy. *The Journal of Negro Education*, 75(3), 506-518.
6. Rotgans, J. I., & Schmidt, H. G. (2011). Situational interest and academic achievement in the active-learning classroom. *Learning and Instruction*, 21(1), 58-67.
7. Kimonen, E., & Nevalainen, R. (2005). Active learning in the process of educational change. *Teaching and Teacher Education*, 21(6), 623-635.
8. Weltman, D., & Whiteside, M. (2010). Comparing the effectiveness of traditional and active learning methods in business statistics: Convergence to the mean. *Journal of Statistics Education*, 18(1). Retrieved from: http://eric.ed.gov/?id=EJ892398.
9. Dewey, J. (1938). *Experience and education*. New York: Collier Macmillan.
10. Piageat, J. (1999). *The psychology of intelligence*. New York: Taylor & Francis.
11. Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Cambridge: Harvard University Press.
12. Ernest, P. (1994). Varieties of constructivism: Their metaphors, epistemologies and pedagogical implications. *Hiroshima Journal of Mathematics Education*, 2, 1-14.
13. UNICEF. (2000). Defining quality in education. *Working paper series,*

education section, the international working group on education Florence, Italy June 2000. Retrieved from: http://www.unicef.org/education/files/QualityEducation.PDF.

14. Marx, A., Fuhrer, U., & Hartig, T. (1999). Effects of classroom seating arrangements on children's question-asking. *Learning Environments Research*, 2(3), 249-263.

15. Wannarka, R., & Ruhl, K. (2008). Seating arrangements that promote positive academic and behavioural outcomes: A review of empirical research. *Support for Learning*, 23(2), 89-93.

16. Haghighi, M. M., & Jusan, M. M. (2012). Exploring students' behavior on seating arrangements in learning environment: A review. *Procedia-Social and Behavioral Sciences*, 36, 287-294.

17. Breithecker, D. (2007). Workplace school demands on ergonomic school furniture for today's classroom. Retrieved from: http://www.lsfurnishings.com/pdfs/VS/%2BBAG7_Educational_Workplace_long_US.pdf.

18. Fullerton, E. K., & Guardino, C. (2010). Teacher and students' perceptions of a modified inclusion classroom environment. *Electronic Journal for Inclusive Education*, 2(5), Retrieved from: http://www.amstat.org/publications/jse/v18n1/weltman.pdf.

19. Guardino, C., & Antia, S. D. (2012). Modifying the classroom environment to increase engagement and decrease disruption with students who are deaf or hard of hearing. *Journal of Deaf Studies and Deaf Education*, 17(4), 518-533.

20. IOS. (1979). ISO5970: Furnitures - chairs and tables for educational institutions - functional sizes. Switzerland: International Organization for Standardization.

21. Chung, J. W., & Wong, T. K. (2007). Anthropometric evaluation for primary school furniture design. *Ergonomics*, 50(3), 323-334.

22. Evans, W. A., Courtney, A. J., & Fok, K. F. (1988). The design of school furniture for Hong Kong schoolchildren: An anthropometric case study. *Applied Ergonomics*, 19(2), 122-134.

23. Parcells, C., Stommel, M., & Hubbard, R. P. (1999). Mismatch of classroom furniture and student body dimensions: Empirical findings and health implications. *Journal of Adolescent Health*, 24(4), 265-273.

24. Legg, S. J., Pajo, K., Sullman, M., & Marfell-Jones, M. (2003). Mismatch between classroom furniture dimensions and student anthropometric

characteristics in three New Zealand secondary schools. In *Proceedings of the 15th Congress of the International Ergonomics Association, Ergonomics for Children in Educational Environments Symposium*, Seoul, 395-397.

25. Lin, R., & Kang, Y. Y. (2000). Ergonomic design of desk and chair for primary school students in Taiwan. In *Proceedings of the Fourth International Conference on Universal Access in Human Computer Interaction: Coping with Diversity*, Taipei, 207-216.
26. UNESCO. (2015). Education for all 2015-2020: Achievements and challenges. United Nations Educational, Scientific and Cultural Organization Publishing. Retrieved from: http://unesdoc.unesco.org/images /0023/002322/232205e.pdf.
27. Adewole, N. A., & Isedowo, B. (2012). Excel interface utilization in automation of design process of ergonomic classroom furniture for primary school pupils in Nigeria. *International Journal of Scientific and Engineering Research*, 3, 388-396.
28. Castellucci, H. I., Arezes, P. M., & Viviani, C. A. (2010). Mismatch between classroom furniture and anthropometric measures in Chilean schools. *Applied ergonomics*, 41(4), 563-568.
29. Diep, N. B. (2003). *Evaluation of fitness between school furniture and children body size in two primary schools in Haiphong, Vietnam*. Master Thesis, Vietnam: Lulea University of Technology.
30. Panagiotopoulou, G., Christoulas, K., Papanckolaou, A., & Mandroukas, K. (2004). Classroom furniture dimensions and anthropometric measures in primary school. *Applied Ergonomics*, 35(2), 121-128.
31. Gouvali, M. K., & Boudolos, K. (2006). Match between school furniture dimensions and children's anthropometry. *Applied ergonomics*, 37(6), 765-773.
32. Mohamed, S. A. A. R. (2013). Incompatibility between students' body measurements and school chairs. *World Applied Sciences Journal*, 21(5), 689-695.
33. Dhara, P. C., Khaspuri, G., & Sau, S. K. (2009). Complaints arising from a mismatch between school furniture and anthropometric measurements of rural secondary school children during classwork. *Environmental Health and Preventive Medicine*, 14(1), 36-45.
34. Domljan, D., & Grbac, I. (2008). Classroom furniture design-correlation of pupil and chair dimensions. *Collegium Antropologicum*, 32(1), 257-265.

35. Hafezi, R., Mirmohammadi, S. J., Mehrparvar, A. H., & & Akbari, H. (2010). An analysis of anthropometric data on Iranian primary school children. *Iranian Journal of Public Health*, 39(4), 78.

36. Feathers, D., Pavlovic-Veselinovic, S., & Hedge, A. (2013). Measures of fit and discomfort for elementary school children in Serbia. *Work*, 44, 73-81.

37. Tunay, M., & Melemez, K. (2008). An analysis of biomechanical and anthropometric parameters on classroom furniture design. *African Journal of Biotechnology*, 7(8), 1081-1086.

38. Purwaningrum, L., Aryani, S., Mulyadi, & Yassierlie. (2011). The product design evaluation of elementary school furniture. In *Proceeding of The 4th International Product Design and Development in Conjunction with The 4th AUN/SEED-Net Regional Conference of Manufacture*. Yogyakarta.

39. Rosyidi, C. N., Susmartini, S., Purwaningrum, L., & Muraki, S. (2014). Mismatch analysis of elementary school desk and chair key characteristics in Indonesia. *Applied Mechanics and Materials*, 660, 1057-1061.

40. Yanto, E., Situmorang, H., Siringoringo, H., & Deros, B. M. (2008). Mismatch between school furniture dimensions and student's anthropometry: A cross-sectional study in an elementary school, Tangerang, Indonesia. In *Proceedings of the 9th AsiaPasific Industrial Engineering & Management Systems Conference*. Indonesia.

41. Kementrian P. D. K. (2015). *Mission and vision, strategic planning of Indonesian education 2015 - 2019*. Ministry of Education, Indonesia.

42. Oyewole, S. A., Haight, J. M., & Freivalds, A. (2010). The ergonomic design of classroom furniture/computer work station for first graders in the elementary school. *International Journal of Industrial Ergonomics*, 40(4), 437-447.

43. Ministry of National Education of Republic of Indonesia. (2007). *Regulation of Ministry of National Education of Republic of Indonesia no. 24 year 2007 about standard of facilities and infrastructure for elementary school*. Jakarta, Indonesia.

44. Bridger, R. (2008). Design and evaluation of manual handling task. In *Introduction to ergonomics*, 215-226. London: CRC Press.

45. Sander, M. (1979). Weight of schoolbags in a Freiburg elementary school: Recommendations to parents and teachers. *Offentliche Gesundheitswes*, 41(5), 251-253.

46. Hong, Y., & Brueggemann, G. P. (2000). Changes in gait patterns in 10-year-

old boys with increasing loads when walking on a treadmill. *Gait and Posture*, 11, 254-259.

47. Snook, S. H., & Ciriello, V. M. (1991). The design of manual handling tasks: Revised tables of maximum acceptable weights and forces. *Ergonomics*, 34 (9), 1197-1213.

48. Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics*, 28 (9), 1347-1362.

49. Nottrodt, J. W., & Manley, P. (1989). Acceptable loads and locomotor patterns selected in different carriage methods. *Ergonomics*, 32(8), 945-957.

50. LaFiandra, M., Wagenaar, R. C., Holt, K. G., & Obusek, J. P. (2003). How do load carriage and walking speed influence trunk coordination and stride parameters. *Journal of Biomechanics*, 36(1), 87-95.

51. National Institute for Occupational Safety and Health. (1981). NIOSH-Work practices guide for manual lifting. *Public Health Services*, 81-122.

52. Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. *Ergonomics*, 36(7), 749-776.

53. Drury, C. G. (1980). Handles for manual materials handling. *Applied Ergonomics*, 11(1), 35-42.

54. Mital, A., & Okolie, S. T. (1982). Influence of container shape, partitions, frequency, distance, and height level on the maximum acceptable amount of liquid carried by males. *American Industrial Hygiene Association Journal*, 43(11), 813-819.

55. Sigholm, G., Herberts, P., Almström, C., & Kadefors, R. (1983). Electromyographic analysis of shoulder muscle load. *Journal of Orthopaedic Research*, 1(4), 379-386.

56. Yasojima, T., Kizuka, T., Noguchi, H., Shiraki, H., Mukai, N., & Miyanaga, Y. (2008). Differences in EMG activity in scapular plane abduction under variable arm positions and loading conditions. *Medicine and Science in Sports and Exercise*, 40(4), 716-721.

57. Sporrong, H., Palmerud, G., & Herberts, P. (1995). Influences of handgrip on shoulder muscle activity. *European Journal of Applied Physiology and Occupational Physiology*, 71(6), 485-492.

58. Alpert, S. W., Pink, M. M., Jobe, F. W., McMahon, P. J., & Mathiyakom, W. (2000). Electromyographic analysis of deltoid and rotator cuff function

under varying loads and speeds. *Journal of Shoulder and Elbow Surgery*, 9(1), 47-58.
59. Waterlow, J., C., Buzina, R., Keller, W., Lane, J., M., Nichaman, M., Z., & Tanner, J., M. (1977). The presentation and use of height and weight data for comparing the nutritional status of groups of children under the age of 10 years. *Bulletin of the World Health Organization*, 55, 489-498.
60. Tanner, J. M., Whitehouse, R. H., & Takaishi, M. (1966). Standards from birth to maturity for height, weight, height velocity, and weight velocity: British children, 1965. I. *Archives of Disease in Childhood*, 41(219), 454.
61. Li, J. X., Hong, Y., & Robinson, P. D. (2003). The effect of load carriage on movement kinematics and respiratory parameters in children during walking. *European Journal of Applied Physiology*, 90(1-2), 35-43.
62. O'Loughlin, J., Gray-Donald, K., Paradis, G., & Meshefedjian, G. (2000). One-and two-year predictors of excess weight gain among elementary schoolchildren in multiethnic, low-income, inner-city neighborhoods. *American Journal of Epidemiology*, 152(8), 739-746.
63. Saarni, L., Nygård, C. H., Kaukiainen, A., & Rimpelä, A. (2007). Are the desks and chairs at school appropriate?. *Ergonomics*, 50(10), 1561-1570.
64. Geldhof, E., De Clercq, D., De Bourdeaudhuij, I., & Cardon, G. (2007). Classroom postures of 8-12 year old children. *Ergonomics*, 50(10), 1571-1581.
65. Ministry of National Education and Regulation of Ministry of National Education of Republic of Indonesia. (2011). *Standard and technical specification of rebuilding broken classroom, construction of new classroom and furnitures, and construction of library and furniture for elementary school/elementary school of children with disabilities*. Jakarta: Ministry of National Education of Republic of Indonesia.
66. BSN. (2011). Wood and wood products-part 19: Learning to primary schools' chairs, In *ICS 97.140*. Jakarta: Badan Standardisasi Nasional. Retrieved from: http://sisni.bsn.go.id/index.php?/sni_main/sni/index_sub9_ics_sni/97.140/474.
67. Yosita, L. (2006). Preliminary study to primary education facilities: A comparison study between Indonesia and development countries. *Dimensi Teknik Arsitektur*, 34(2), 122-132.
68. Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. London: Sage Press.

69. Sheskin, D. J. (2004). *Handbook of parametric and nonparametric statistical procedures*. New York: CRC Press.

70. Cotton, L. M., O'Connell, D. G., Palmer, P. P., & Rutland, M. D. (2002). Mismatch of school desks and chairs by ethnicity and grade level in middle school. *Work*, 18(3), 269-280.

71. Chuan, T. K., Hartono, M., & Kumar, N. (2010). Anthropometry of the Singaporean and Indonesian populations. *International Journal of Industrial Ergonomics*, 40(6), 757-766.

72. Habicht, J. P., Martorell, R., Yarbrough, C., Malina, R. M., & Klein, R. E. (1974). Height and weight standards for preschool children: How relevant are ethnic differences in growth potential?. *The Lancet*, 1(7858), 611-614.

73. Graitcer, P. L., & Gentry, E. M. (1981). Measuring children: One reference for all. *The Lancet*, 2(8241), 297-299.

74. Ministry of Education, Culture, Sports, Science and Technology of Japan. *Physical fitness and motor ability investigation*. (2014). Retrieved from: http://www.e-stat.go.jp/SG1/estat/NewList.do?tid=000001016672.

75. Ministry of Internal Affairs and Communications Statistics Bureau of Japan. *Physical fitness and motor ability investigation in 2013*. Retrieved from: http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001055014&cycode=0.

76. Ministry of Education, Culture, Sports, Science and Technology of Japan. *Guidebook for Starting School*. (2005). Retrieved from: http://www.mext.go.jp/component/english/__icsFiles/afieldfile/2011/03/17/1303764_008.pdf.

77. Rebok, G., Riley, A., Forrest, C., Starfield, B., Green, B., Robertson, J., & Tambor, E. (2001). Elementary school-aged children's reports of their health: A cognitive interviewing study. *Quality of Life Research*, 10(1), 59-70.

78. Beenakker, E. A. C., Van der Hoeven, J. H., Fock, J. M., & Maurits, N. M. (2001). Reference values of maximum isometric muscle force obtained in 270 children aged 4-16 years by hand-held dynamometry. *Neuromuscular Disorders*, 11(5), 441-446.

79. Sanders, E. N. (1999). Postdesign and participatory culture. In *Proceedings of the International Conference 'Useful and critical'-The position of research in design*. Helsinki, Finland.

80. Sanders, E. N. (2002). From user-centered to participatory design approaches. In Frascara, J. (Eds.), *Design and the social sciences* (1-8). New York: CRC Press.

81. Green, W., & Jordan, P. W. (Eds). (1999). *Human factors in product design:*

Current practice and future trends. New York: CRC Press.
82. Jordan, P. W. (2002). *Designing pleasurable products: An introduction to the new human factors*. New York: CRC Press.
83. Kuijt-Evers, L. M., Twisk, J., Groenesteijn, L., De Looze, M. P., & Vink, P. (2005). Identifying predictors of comfort and discomfort in using hand tools. *Ergonomics*, 48(6), 692-702.
84. Jung, H. S., & Jung, H. S. (2003). Development and ergonomic evaluation of polypropylene laminated bags with carrying handles. *International Journal of Industrial Ergonomics*, 31(4), 223-234.
85. Kong, Y. K., & Lowe, B. D. (2005). Optimal cylindrical handle diameter for grip force tasks. *International Journal of Industrial Ergonomics*, 35(6), 495-507.
86. Grant, K. A., Habes, D. J., & Steward, L. L. (1992). An analysis of handle designs for reducing manual effort: The influence of grip diameter. *International Journal of Industrial Ergonomics*, 10(3), 199-206.
87. Roman-Liu, D. A., & Tokarski, T. Z. (2002). EMG of arm and forearm muscle activities with regard to handgrip force in relation to upper limb location. *Act of Bioengineering and Biomechanics*, 4(2), 33-48.
88. Basmajian, J. V., & Blumenstein, R. (1980). Anatomical drawing by regions. *In Electrode placement in EMG biofeedback*, 53-69. Michigan: Williams & Wilkins.
89. Criswell, E. (2010). Chapter 17: Electrode placements. *In Cram's introduction to surface electromyography*, 257-381, Massachusetts: Jones & Bartlett Publishers.
90. Ervilha, U. F. (2012). A simple test of muscle coactivation estimation using electromyography. *Brazilian Journal of Medical and Biological Research*, 45(10), 977-981.
91. Kendall, H. O., & McCreary E. K. (1983). Muscles, testing and function. *American Journal of Physical Medicine and Rehabilitation*, 28(2), 326.
92. Hislop, H., & Montgomery, J. (2012). *Daniels and Worthingham's muscle testing: Techniques of manual examination and performance testing*. Amsterdam, Netherlands: Elsevier Health Sciences.
93. Boettcher, C. E., Ginn, K. A., & Cathers, I. (2008). Standard maximum isometric voluntary contraction tests for normalizing shoulder muscle EMG. *Journal of Orthopaedic Research*, 26(12), 1591-1597.
94. Roman-Liu, D., Tokarski, T., & Kamińska, J. (2001). Assessment of the

musculoskeletal load of the trapezius and deltoid muscles during hand activity. *International Journal of Occupational Safety and Ergonomics*, 7(2), 179-193.

95. Sharkey, N. A., Marder, R. A., & Hanson, P. B. (1994). The entire rotator cuff contributes to elevation of the arm. *Journal of Orthopaedic Research*, 12(5), 699-708.

96. Anderson, A. M., Meador, K. A., McClure, L. R., Makrozahopoulos, D., Brooks, D. J., & Mirka, G. A. (2007). A biomechanical analysis of anterior load carriage. *Ergonomics*, 50(12), 2104-2117.

97. Inman, V. T., & Abbott, L. C. (1996). Observations of the function of the shoulder joint. *Clinical Orthopaedics and Related Research*, 330, 3-12.

98. Kronberg, M., Nemeth, G., & Brostrom, L. A. (1990). Muscle activity and coordination in the normal shoulder: An electromyographic study. *Clinical Orthopaedics and Related Research*, 257, 76-85.

99. Chaffin, D. B. (1973). Localized muscle fatigue-definition and measurement. *Journal of Occupational and Environmental Medicine*, 15(4), 346-354.

100. Herberts, P., Kadefors, R., & Broman, H. (1980). Arm positioning in manual tasks: An electromyographic study of localized muscle fatigue. *Ergonomics*, 23(7), 655-665.

101. National Institute of Advanced Industrial Science and Technology, Japan. (2014). *Japanese body dimension 1991-1992*. Retrieved from: https://www.dh.aist.go.jp/ database/91-92/data/list.html.

102. Research Institute of Human Engineering for Quality Life, Japan. (2010). *Human hand dimensions data for ergonomics design 2010*, Retrieved from: http://www.hql.jp.

103. Drury, C. G., Deeb, J. M., Hartman, B., Woolley, S., Drury, C. E., & Gallagher, S. (1989). Symmetric and asymmetric manual materials handling part 1: Physiology and psychophysics. *Ergonomics*, 32(5), 467-489.

Acknowledgement

First and foremost, I would like to express my deepest gratitude to my supervisor Prof. Satoshi Muraki for the continuous support of my doctoral study and research, for his patience, encouragement, and professional knowledge supporting me finishing this dissertation.

I would like to thank the rest of my dissertation committee: Professor Shigekazu Higuchi and Professor Takafumi Maeda, for reviewing and insightful comments.

In particular, I am grateful to Dr. Cucuk Nur Rosyidi for encouraging and supporting this research. Thank you very much also to Dr. Kyotaro Funatsu for involving and supporting in particular study of this dissertation.

I am grateful to everyone who gave their attention, skills, and time to this study. I would like to thank Engr. N.A. Adewole Ph.D. (Nigeria), Ms. Renata Zoraifi, S.E., Ak., M.Si. (Australia), Ms. Emilia Abu Bakar (Malaysia), Nguyen Bich Diep, M.Sc., Ph.D. (Vietnam), Miss Muchsonah, S.Pd., M.Ed., App. Ling (UK) for their contributions of elementary school classrooms photos and descriptions of current environments. Thank you very much for the parents who have involved and permitted their children as participants in the experiments, and for the children participants.

I also thank very much for my labmates in Professor Muraki's laboratory who have supported and helped me finishing this dissertation, especially Dr. Jinghong Xiong, Mr. Ping Yeap Loh, Mr. Tomoaki Yokota, Mr. Hiroki Nakashima, Mr. Kyou Chyou, Miss Irma Nur Afiah, and Ms. Nursalbiah.

I would like to thank my family: my husband, Suparjito, my children, Zaidan Thoriq Attaqy, Aisya Faradiba Kamila, Izzuddin Abdurrahman Al-ghiffari, my parents, and big family in Indonesia, supporting me to complete my doctoral study.

Finance support during my study was provided by scholarship program of Ministry of Education, Republic of Indonesia, and by the assistance fundings of Sebelas Maret University.