Development of a Student Chair for Promoting the Physical Growth and Safety

- 신체발육과 안전 증진을 위한 학생용 의자 개발 -

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Abstract

우리의 식생활 및 주거 환경이 향상됨에 따라 과거에 비해 학생들의 체격이 커지고 체형 또한 점차 서구화 되가는 경향을 보이고 있으나 아직까지도 초·중·고등학교에서는 학생 자신의 체격에 적합하게 조절하여 사용할 수 없는 고정형 의자를 사용하고 있다. 이에 따라 학생들의 신체발육에 지장을 초래 할 수 있으며 특히 요통과 같은 허리에 문제를 일으킬 수 있다. 따라서 본 연구에서는 학생 자신의 체격에 맞게 높낮이를 자유롭게 조절하여 사용할 수 있는 학생용 의자를 개발하였다. 개발된 조절형 의자는 일반적으로 사용하는 학생용 의자의 다리부분에 풀림과 조임이 가능한 금속제 나사형식의 높이조절봉을 도입하여 공구가 필요 없이 손으로 회전시켜 좌판의 높이를 자유롭게 조절하여 사용할 수 있게 설계 하였다. 또한 의자 등받이는 전·후·상·하 방향으로 이동되게 함으로써 착석 시 좌판의 깊이와 등받이의 높낮이를 동시에 한번의 동작으로 조절 가능하게 하였다. 한편 개발된 조절형 의자는 현재 우리나라에서 채택하여 사용하고 있는 ISO 5970(Standards for tables and chairs for educational institutions)과 비교하여 수용능력에 따른 적합성 여부를 평가하였으며 피실험자 40명을 대상으로 fitting trials를 실시하였다. 평가결과 개발된 조절형 의자는 두가지 평가기준에 적합하였으며 실용화 가능성을 발견하였다. 향후 이를 각급 학교 및 학원에 보급 활용함으로써 학생들의 이상체형 형성을 억제하여 신체 발육과 안전을 도모할 수 있으며 학습효과 또한 높일 수 있다고 판단된다.

Keyword : Adjustable chair, Student chair, ISO 5970, Fitting trials.

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1. Introduction

Even though the average physical dimensions of students have increased due to changes in living standards and dietary habits, the size of chairs remains the same. According to Bradford et al.(1994) and Drury and Coury(1982), using improperly designed chairs for extended periods of time not only interferes with students' somatic growth, but also hampers their learning abilities since they're unable to concentrate due to being uncomfortable. Moreover, if this situation continues, it is highly probable it can lead to intervertebral disk degeneration.

Therefore, more research is being done on chairs for students, and the need for adjustable chairs is becoming increasingly important(Evans et al., 1988; Mandal, 1982). Sanders and McCormick(1992) point out that adjustable furniture is fundamental to developing and maintaining good posture. Adjustable seats increase productivity(Springer, 1982) and reduce the risk of shoulder and back pain(Shute and Starr, 1984). Thus, various types of adjustable chairs for students are being developed and made available on the marketplace.

The problem, however, is that people rarely use the adjustable features of their chairs because they're not aware of them(Sanders and McCormick, 1992). In a survey of 2,000 air traffic controllers, Kleeman and Prunier(1980) found only about 10% adjusted their seats during the day, and more than half were not even aware of some of the adjustments that were available. One reason why people are reluctant to adjust their furniture is that the adjustments are not always easy. Moreover, adjustable furniture often has limited adjustable parts, and is expensive.

Lueder(1986) provides the following guidelines for making adjustments easier: controls should be easy to reach and adjust from the standard seated position, labels and instructions on the furniture should be easy to understand, controls should be easy to locate and use, the need for other tools unnecessary, controls should produce the desired results, minimal movement should be required to use the controls, and adjustments should require the use of only one hand.

The development and distribution of adjustable chairs with the aforementioned functions are essential for maintaining good posture which promotes better learning. The market demand for such furniture is expected to be enormous in the near future. The objective of this study is to develop adjustable chair for students using the guidelines provided by Lueder(1986), and to evaluate their suitability based on their adoptability as compared with dimensions provided by the ISO 5970(Standards for tables and chairs for educational institutions). The study was also done to determine its practicality based on the results of the fitting trials.

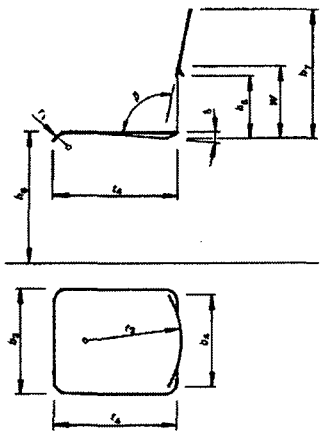
2. Methods and Procedures

The ISO 5970 distinguishes the sizemark from 0 to 6 depending on the average body height in order to determine the appropriate size for tables and chairs. According to this international standard, the 7 sizes for seating and related tables meet the seating requirements in all educational institutions. Therefore, the design adoptability, according to this study, ranges from sizemark 0 to 6 of the ISO 5970 in relation to the average height of a user which is between 900 and 1800mm.

This study considered the most significant problems stated by Sanders and McCormick(1992): "adjustments are not easy" and "people do not usually bother to adjust their seats. an average user could become overwhelmed by the all possible adjustments that could be made." The study attempted to reduce the inconvenience caused by the structural faults by minimizing the added adjustable parts.

The following supplementary design criteria were also added: production costs should not be much higher than those of existing chairs; design a stable and solid structure; create a design that requires minimal movement, and needs no tool for an adjustment; no restrictions on the adjustable interval; minimum use of parts to reduce weight for easier mobility.

The angle of the seat for the backrest and seat pan, the inclination of the backrest, and the radius of the backrest, were complied according to the recommendation of the ISO 5970. Figure 1 shows the section and plan of the dimensions of chair, and Table 1 show the recommended dimensions of the ISO 5970 in accordance with the symbols in Figure 1.



< Figure 1 > Dimensions of a chair in section and plan(adapted from ISO 5970)

< Table 1 > Dimensions of the ISO 5970-Seating

Dimensions in mm

Classification		Symbol in Figure 1	Sizemark						
			0	1	2	3	4	5	6
Reference stature - average body height		-	900	1050	1200	1350	1500	1650	1800
Height of seat		h5	220	260	300	340	380	420	460
Effective depth of seat		t4	-	260	290	330	360	380	400
Minimum width of seat		b3	-	250	270	290	320	340	360
Reference point for β		w	-	160	170	190	200	210	220
Maximum height to bottom of backrest		h6	-	120	130	150	160	170	190
Height to top of backrest	Min	h1	-	210	250	280	310	330	360
	Max		-	250	280	310	330	360	400
Minimum width of backrest		b4	-	250	250	250	280	300	320
Radius of front edge of the seat		r1	-	30 to 50					
Minimum radius of backrest		r2	-	300					
Angle of seat		δ	-	0° to 4°					
Inclination of backrest		β	-	95° to 106°					

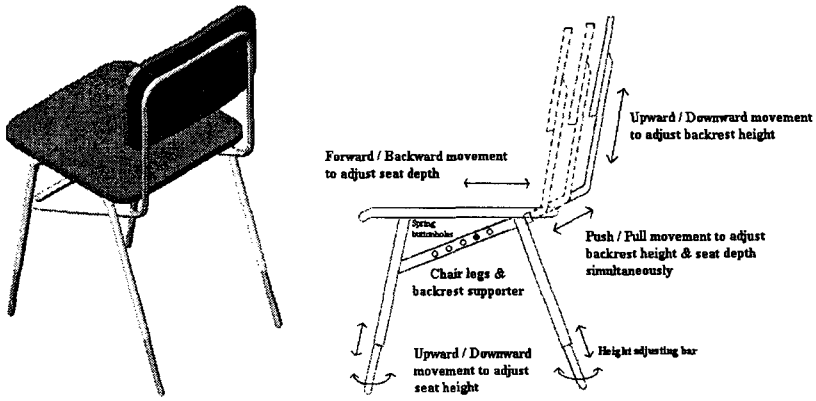
- means not applicable or not specified

Since anthropometry data varies from population to population, different countries have developed their own standards for designing chairs and tables for educational institutions. The ISO 5970-1979(E)(Chairs and tables for educational institutions - functional sizes), which is the most commonly adopted standard in most countries, is used in this study. The present ISO 5970 classifies the sizemark according to the user's average body height to provide the specific standards for tables and chairs. Therefore, the final adjustable range limit will be determined after conducting the relative comparison evaluation of adoptability based on design standards suggested by the ISO 5970.

3. Development of an Adjustable Chair

Based on the design criteria in Chapter 2, Figure 2 shows the adjustable student chair developed in this study along with the simulation of a pulling out backrest which can be adjusted according to the students' physical dimensions.

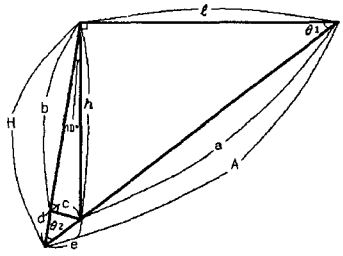
The Figure 2 also shows the height adjusting bar on the chair which sets the height to one's sitting popliteal height. There are marked scales on the height adjusting bar so the height of all four legs can be evenly adjusted. The backrest is inserted into the chair legs and backrest supporter at the bottom part of the seat pan for forward/backward and upward/downward movement. This allows the entire backrest area to move forward/backward and upward/downward so that the height of the backrest and the depth of the seat can be adjusted simultaneously.



< Figure 2 > Developed adjustable student chair and simulation of a pulling out backrest in sectional view

To adjust the backrest, the spring button, located on the chair legs and both sides of the backrest supporter, has to be pressed. Then the backrest adjusting part has to be pushed or pulled until the spring button pops out of the holes on the chair legs and on the backrest supporter. The spring buttonhole interval is set at 20mm which is the minimum.

The following method was applied to determine the appropriate slope angle of the chair legs and backrest supporter while allowing for simultaneous forward/backward and upward/downward adjustments. For stability, the slopes of the front and back legs of the chair are set at 10° to 20° in relation to the seat pan instead of being perpendicular. The back rest has been inserted into the chair legs and backrest supporter so the backrest can be moved forward/backward and upward/downward(part A in Figure 3).



< Figure 3 > The triangular shape of the chair legs and backrest supporter

This forms the triangular shape which consists of the length between the front and back legs(ℓ), the chair legs and backrest supporter(A), and the front legs of the chair(H). The length between the front and back legs of the bottom part of

the seat pan is defined as ℓ, and the height(h), based on the angle variation, can be calculated by $\ell * tan\theta 1$ the length of the slope(a) is $\ell / cos\theta 1$ or by $\sqrt{\lambda^2 + h^2}$.

When the slope angle of the chair legs and backrest supporter is $\theta 1$ as in Figure 3, each dimension, excluding the height(h) and slope length(a), can be calculated as follows:

$$b = h * cos 10°;\ c = b * tan 10°;\ d = \frac{c}{tan\theta 2};\ e = \frac{d}{cos\theta 2}.$$

When the Forward/Backward, Upward/Downward adjustment part is moved by being pulled out, as shown in Figure 2, the size variation can be found by using the following formula: Dimension variation of FB distance(A : ℓ = pulling distance : FBD) and Dimension variation of UD height(A : H = pulling distance : UDH).

Therefore, as the angle of the slope($\theta 1$) of the chair legs and backrest supporter increases, the FB pulling distance range decreases. The variation of the UD pulling height, therefore, becomes greater. Table 2 shows the summary of the backrest FBD and UDH variation when the backrest adjusting part is pulled 20mm, while the length between the front and back legs of chair(ℓ) is 240mm.

< Table 2 > Variations of backrest UDH and FBD based on the slope angle of the chair legs and backrest supporters

Dimensions in mm

Slope angle($\theta 1$)	Height(H)	Slope length(A)	Upward/Downward Height(UDH)	Forward/Backward Distance(FBD)	Ratio(UDH/FBD)
20	94.7834	272.9179	6.9459	17.5877	0.3949
21	100.3402	275.7383	7.2779	17.4078	0.4181
22	106.0147	278.7034	7.6077	17.2226	0.4417
23	111.8144	281.8197	7.9352	17.0322	0.4659
24	117.7471	285.0943	8.2602	16.8365	0.4906
25	123.8212	288.5348	8.5828	16.6358	0.5159
30	156.6489	308.5381	10.1543	15.5572	0.6527

The chair developed in this study not only allow the height of the backrest to be adjusted, but also make it possible to adjust the depth of the seat simultaneously. Therefore, the appropriate slope angle of the chair legs and backrest can be decided when the ratio of the UDH and the FBD is similar to the ratio of the height of the backrest and the seat depth as recommended by the ISO 5970.

Since this study focused on satisfying the design criteria provided by the ISO 5970, the calculated result of the ratio of the maximum height to the bottom of the backrest and the depth of seat is shown in Table 3. Based on the slope angle of the chair legs and backrest supporter, the ratio of the backrest UDH and FBD is

23° of 0.4659 as seen in Table 2. This shows the least difference compared with the ISO 5970 chair sizemark 0~6 on the average backrest height and the depth ratio of the seat pan 0.4552 as shown in Table 3.

< Table 3 > The ratio of maximum height to bottom of backrest and effective depth of seat(ISO 5970-sitting)

Dimensions in mm

Sizemark	Backrest height* (BRH)	Seat pan depth** (SPD)	Height to depth ratio (BRH/SPD)
0	-	-	-
1	120	260	0.4615
2	130	290	0.4483
3	150	330	0.4545
4	160	360	0.4444
5	170	380	0.4474
6	190	400	0.4750
Mean	153.33	336.67	0.4552

* maximum height to bottom of backrest; ** effective depth of seat

Therefore, the slope angle($\theta 1$) of the chair legs and backrest supporter can be set as 23°. Thus, the adjustable chair can meet international standards as long as the slope of the chair and the backrest supporter are adjusted accordingly.

To be compatible with ISO 5970, 23° is the appropriate slope angle($\theta 1$) for the chair legs and backrest supporter, while $\theta 2$ becomes 57°. Table 4 shows the specific dimensions of the height(H) parts, the chair legs, and the backrest supporter(A). These vary depending on the length(ℓ) of the front and back chair legs.

< Table 4 > Specific dimensions based on the length between the front and back legs

Dimensions in mm

Length (ℓ)	h $(\lambda * \tan\theta 1)$	a $\frac{\lambda}{(\cos\theta 1)}$	b $(h * \cos 10°)$	c $(b * \tan 10°)$	d $\frac{c}{(\tan\theta 2)}$	e $\frac{d}{(\cos\theta 2)}$	H $(b+d)$	A $(a+e)$
240	101.8740	260.7265	100.3263	17.6902	11.4882	21.0932	111.8144	281.8197
250	106.1187	271.5901	104.5065	18.4273	11.9668	21.9721	116.4734	293.5622
260	110.3635	282.4537	108.6868	19.1644	12.4455	22.8509	121.1323	305.3046
270	114.6082	293.3173	112.8670	19.9015	12.9242	23.7298	125.7912	317.0471
280	118.8529	304.1809	117.0473	20.6386	13.4029	24.6087	130.4502	328.7896
290	123.0977	315.0445	121.2276	21.3757	13.8815	25.4876	135.1091	340.5321
300	127.3424	325.9081	125.4078	22.1128	14.3602	26.3665	139.7680	352.2746
310	131.5872	336.7717	129.5881	22.8499	14.8389	27.2454	144.4270	364.0171
320	135.8319	347.6353	133.7683	23.5870	15.3176	28.1242	149.0859	375.7596

Referring to the data in Table 4, when the slope angle($\theta 1$) is 23° and the

pulling distance is 20~200mm, the FB movement distance(A : ℓ = pulling distance :FBD) and UD movement height(A : H = pulling distance : UDH) can be calculated. The variation of the calculated result of the backrest UDH and FBD depend on the pulling distance of backrest as shown in Table 5.

< Table 5 > Variations of backrest UDH and FBD based on the pulling distance of backrest

Dimensions in mm

Pulling distance of backrest	Upward/Downward Height	Forward/Backward Distance
20	7.9352	17.0322
40	15.8704	34.0643
60	23.8055	51.0965
80	31.7407	68.1287
100	39.6759	85.1608
120	47.6111	102.1930
140	55.5462	119.2252
160	63.4814	136.2573
180	71.4166	153.2895
200	79.3518	170.3217

4. Determination of the Adoptability Based on the ISO 5970

The adoptability of the developed chair was evaluated based on the suggested dimensions of the ISO 5970. As seen in Table 6, the chair adjustment range needs to be 240mm since its seat pan height is 220~460mm. However, if the pulling distance of the backrest becomes too long, a structural problem such as the pulling part being bent as weight is added, may occur.

< Table 6 > Design ranges of the chair in accordance with the ISO 5970

Dimensions in mm

Classification	Minimum dimension	Maximum dimension	Required design range	Adjustable sizemark 1	Adjustable sizemark 2	Required dimension per sizemark
Sizemark	0	6	7	0-3	3-6	4
Reference stature	900	1800	900	900-1350	1350-1800	450
Height of seat	220	460	240	220-340	340-460	120
Height of backrest*	120	190	70	120-155	155-190	35
Effective depth of seat	260	400	140	260-330	330-400	70
Min. width of seat	250	360	110	250-305	305-360	55

* maximum height to bottom of backrest

Hence, the appropriate pulling distance should be within the range of 180mm. Regarding chairs, to which more weight is added, the adjustable range of 120mm

is recommended although it is possible to accommodate the design dimensions presented in the ISO 5970 as one standard. Therefore, applying the two design sizemarks(adjustable sizemark 1 = ISO 5970 sizemark 0~3 accommodation; adjustable sizemark 2 = ISO 5970 sizemark 3~6 accommodation) is recommended for stability and safety.

5. Subjective Fitting Trials of an Adjustable Chair

The technique of fitting trials has been found to produce results comparable to anthropometric recommendations. Therefore, fitting trials were used in this study as a means of structuring the user's first interaction with the constructed chair.

Forty subjects divided into two groups of 20 were used in the fitting trials. The first group, consisting of 13 male and 7 female elementary school students under 135cm, tested the adjustable chair sizemark 1. The second group, consisting of 14 male and 6 female middle and high school students over 135cm, tested the adjustable chair sizemark 2. Table 7 shows the selected subjects' demographic data.

< Table 7 > Subject's demographic data classified into two different stature groups

Classification		Age(yr)	Height(cm)	Weight(kg)
Group 1 (n=20)	Range	7~12	119.50~135.00	22.20~48.00
	Mean(SD)	9.70(1.45)	131.23(4.67)	29.60(5.29)
Group 2 (n=20)	Range	13~17	135.50~181.00	39.00~77.00
	Mean(SD)	15.00(1.45)	165.12(10.66)	59.56(9.25)

As noted by Shackel et al.(1969), five minutes is considered sufficient for a user to become familiar with a chair. Subjects were thus allowed five minutes to experiment with two available adjustments(seat height and simultaneous adjustment for seat depth and backrest height) until they felt comfortable. The experiment took place over two consecutive days. After five minutes of each fitting trial, a surveyor recorded the comfortable positions chosen by the same subjects on different days.

Table 8 shows the ranges and mean differences of the comfortable positions found in the fitting trials. The low, mean difference values imply that the chair fell within the range of subjective comfortable fitting dimensions, a range consistent with the static dimensions originally specified in the previous section. This shows that the adjustments to the chairs were sufficient enough to accommodate the subjects who participated in the experiment.

< Table 8 > Range and mean differences of comfort positions from fitting trials

Classification		Seat height(mm)	Seat depth & backrest height(mm)
Group 1 (Sizemark 1)	Range	0~35.00	0~40.00
	Mean differences	12.80	11.00
Group 2 (Sizemark 2)	Range	0~52.00	0~60.00
	Mean differences	16.05	18.00

6. Discussion and Recommendations

This study focused on an adjustable chair to satisfy the needs of students' physical dimensions based on ergonomic design criteria. The most critical design criteria of the developed chair is to make up for the demerits of existing adjustable chairs by applying the ergonomic design and considering the functional size provided by the ISO 5970. The results of the comparative evaluations and fitting trials proved that such standards can be applied to the developed chair. The latter is recommended for students to help improve their learning ability and maintain proper growth by preventing abnormal body posture.

Since modern societies value a better quality of life, it is recommended that the user-friendly design concept rather than the economical theory be applied in education furniture designs. Therefore, later research will require further development of education furniture designs, designs that are considered aesthetic, comfortable and convenient. The findings of this study should be applied to the designs of not only student chairs, but to home and office furniture as well.

7. References

[1] Bradford, D. S., Lonstein, J. E., Moe, J. H., Ogilvie, J. W., and Winter, R. B., "Moe's textbook of scoliosis and other spinal deformities." 3rd Ed, W.B. Saunders, Philadelphia, (1994).

[2] Drury, C. G. and Coury, B. G., "A methodology for chair evaluation." Applied Ergonomics, 13 (1982) : 195-202.

[3] Evans, W. A., Courtney, A. J., and Fok, K. F., "The design of school furniture for Hong Kong school children." Applied Ergonomics, 19 (1988) : 122-134.

[4] ISO 5970, "Chairs and tables for educational institutions-Functional sizes." International Organization for Standardization, UDC 371.63, (1979).

[5] Kleeman, W. and Prunier, T., "Evaluation of chairs used by air traffic controllers of the U.S. Federal Aviation Administration." NATO symposium on

anthropometry and biomechanics: Theory and application. London: Plenum Press, (1980).

[6] Lueder, R., "Work station design, the ergonomics payoff: designing the electronics office." Toronto, Ontario, Canada: Holt, Rinehart and Winston, 1986.

[7] Mandal, A., "The correct height of school furniture." Human Factors, 24 (1982) : 257-269.

[8] Sanders, M . S. and McCormick, E. J., "Human factors in engineering and design." 7th Ed., McGraw-Hill International Editions, (1992).

[9] Shackel, B., Chidsey, K. D., and Shipley, P., "The assessment of chair comfort." Ergonomics, 12 (1969) : 269-306.

[10] Shute, S. J. and Starr, S. J., "Effects of adjustable furniture on VDT users." Human Factors, 26 (1984) : 157-170.

[11] Springer, T., "Visual display terminals: A comparative evaluation of alternatives." Bloomington, IL: State Farm Mutual Automobile Insurance Co., (1982).

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