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Development of Ergonomic Backrest for Office Chairs

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Objective: This study aims to develop and scientifically investigate the efficacy of the Spine S-curve Reactive Backrest that responds to the spine curvature of the user when seated, and maintains and enhances the natural S-curve of the lower back, thereby helping to relieve fatigue, correct posture and prevent spine deformities.

Background: The focus of current development, design guidelines and/or standards for office chairs is mainly placed on the chair's dimensions, incline angle, adjusting features and lumbar support. Research and development was called for developing a chair backrest that maintains and improves the S-curve of the full spine.

Method: The Spine S-curve Reactive Backrest was ergonomically designed to maintain correct posture and enhance user comfort. When leaned on, the backrest responds to the user's spine line and the whole lower back sits closely against the backrest, thereby aligning the user's lower back and backrest as one to maintain and improve the natural S-curve formation of the spine. In order to evaluate the efficacy of the newly designed chair (new design) and the comparison target (chair), five male college students of standard body type with normal spine curvature were selected as test subjects, and a motion analyzer and electromyography were utilized to measure S-curve and erector spinae muscle activity when seated.

Results: The spine S-curve was better maintained and improved when sitting in the new design than in the comparison chair. Particularly notable was the greater displacement gap of the thoracic spine than the cervical spine, and also that of the lumbar more than the thoracic spine, with the increase of the backrest tilting angle. Furthermore, the electromyogram results showed the new design caused a lower fatigue level of the erector spinae muscles compared to the comparison chair, and also earned a higher preference in the subjective opinion results.

Conclusion: The newly designed chair in this study responds to the user's spine curvature and maintains and enhances the lower back's natural S-curve, and thereby relieves fatigue, promotes better posture, and helps to prevent spine deformities better than existing office chairs. There is a need to widely introduce and supply this new design.

Application: The new design is applicable to office and student chairs, and is expected to improve concentration and work efficiency.

Keywords: Ergonomic seating, Office chair, Backrest, Spine S-curve, Sedentary occupations

1. Introduction

The percentage of sedentary occupations today continues to rise rapidly. Many individuals normally spend more than a third of the day seated in chairs, and longer sitting times lead to lower back discomfort and pain. Although sedentary workers are not required to perform much physical labor, sedentary tasks are reported to be major risk factors of lower back pain (Cartas et al., 1993; Choi et al., 2010; Lengsfeld et al., 2000; van Dieen et al., 2001; Videman et al., 1990). According to Porter (1999), the US has incurred high health costs due to the increase in sedentary jobs, and thus there is keen interest in office chair development and relevant industries.

Efforts persist to develop a more comfortable and relaxing office chair, and user convenience and health are now the key points of technological development. Ergonomic Seating Standards and Chair Designs (ANSI/HFES 100, 2007) states that "The purpose of good seating is to provide stable body support in a dynamic posture which is comfortable over a period of time, physiologically satisfactory, and appropriate to the task or activity which is to be performed". Accordingly, a number of ergonomic design guidelines and standards have been established and implemented (ANSI/HFES 100, 2007; BIFMA G1, 2002; BSR/HFES 100, 2002; CGSB-44.232, 2002; CSA-Z412, 2000; ISO 9241-5, 1999).

However, such chair design guidelines or standards have only reflected chair dimensions, incline angle, adjusting features and lumbar support, thereby necessitating research and development on chair backrests that will maintain and enhance the S-curve of the full spine. A backrest empirically serves to support the back and lower back to distribute upper body weight and relieve lower back fatigue. In other words, a backrest relaxes the erector spinae muscles and lessens stress to the spine. Also, a chair with lumbar support will sustain lumbar lordosis to enhance comfort (Carcone and Keir, 2007; Corlett and Eklund, 1984; Ellegast et al., 2012).

"The back" is the general term used to indicate the body parts that touch a chair backrest, but is inclusive of various spinal parts as well. Thus, this study referred to Wikipedia (http://en.wikipedia.org/) for a more concrete and accurate explanation, and defined the thoracic spine area as the back (upper and mid back areas where the ribs attach to the spinal column) and the lumbar area as the lower back (the region of the back above the waist).

The backrests of conventional office chairs are manufactured to respond to the back-lower back spine curve so as to support the user's back and lower back. However, such chairs are built randomly based on manufacturer's design standards and do not properly reflect the various physical characteristics of users. Consequently, when seated, user A's lumbar will reach the backrest but shoulders and thoracic spine will sit away from the backrest, while the opposite may happen to user B. And when the backrest is tilted, the thoracic spine will flatten and the lumbar will sit away from the lumbar support area of the backrest, and thus the chair loses its back and lower back support feature. This is likely to happen when the backrest does not fit the dimensions or body type of the user's back and lower back, when the backrest does not tilt or is stiff, or when the user has a work habit of pulling the body forwards to the desk.

This results in many office chair users' perception that the backrest does not properly support the back and lower back, and in efforts to resolve their discomfort, supplementary tools such as a cushion, lumbar pillow or towel roll, or backrest prop are frequently placed in the backrest part of the chair. Despite such efforts, however, the improvised backrests fail to adequately support the back and lower back when the user is seated for long periods. Accumulated stress to the lower back leads to bad posture, and may cause lower back pain and even spine deformities.

Carcone and Keir (2007) measured backrest pressure, spinal posture and comfort in reference to supplementary backrest and lumbar pad thicknesses, and found a decrease in lower back pressure and improved lumbar lordosis. Veraga and Page (2000a)

also tested the efficacy of six different backrests, and reported that the percentage (of use) and type of backrest is related to the perception of comfort and discomfort in the lumbar area.

In acknowledgement of the need for a better alternative, private manufacturers have attempted to satisfy the demand for ergonomically designed office chairs. A unique backrest already developed is the Duoback (http://www.duoback.co.kr/). The Duoback chair has two split backrests that run down parallel on both sides of the spine line and cradle-support both sides of the lower back. The main advantage is that the backrest is connected to the chair frame with fluid rubber, which enables the backrest to freely move up, down, left, and right, and is designed to cradle the back without applying pressure to the spine. As such, its marketing point is that it relaxes the lower back and distributes body weight at the same time to help manage lower back health. Nevertheless, the Duoback backrest has level surfaces that can only move up, down, left, and right, and cannot respond to the user's lower back curve, thus making it difficult to provide adequate comfort. Another example is the Responsive Back Technology (RBT) Task Chair developed by Teknion (http://www.teknion.com/). Its backrest takes on the form of the human vertebrae and ribs, and aligns to the spine curve of the seated user to maintain good posture and continues to adjust to the user's lower back. The downsides, however, are its high price as well as some users' aversion to the backrest shape that closely resembles the spine and rib bones.

Patents related to chair backrest development have also been granted to a "waist-supporting device mounted on a chair (Korea patent 0328912, 2002)" and a "chair with adjustable backrest (US patent 3938858, 1976)", expanding the lower back support area accordingly in response to shifts in users' posture. These backrests move linear front to back in the lumbar area, and by being able to respond to the user's front to back movement when performing tasks, can provide significant lower back support. Unfortunately, should the user slightly move out of position to the left or right, or lean back on the backrest, the user's lumbar position will change but the backrest will not properly respond to this change and lower back support will be lost.

As noted, if a chair backrest cannot support the full spine, or if a chair backrest cannot maintain and enhance the original spine curvature, then upper body weight will not distribute evenly, resulting in significant pressure on the lumbar and buttocks. This study, therefore, developed the Spine S-curve Reactive Backrest that responds to the spine form of the user when seated, and so supports the full spine and maintains and enhances the natural S-curve of the lower back, thereby helping to relieve fatigue, correct posture and prevent spine deformities. Moreover, by establishing objective methods and subjective standards to conduct evaluations and scientifically investigate the efficacy of the newly designed backrest, this study sought to promote the lower back health of chair users and contribute to the furthering of research and supply.

2. Methods

2.1 Subjects

Five male college students without physical disabilities were selected as test subjects for the purpose of comparing and evaluating the Spine S-curve Reactive Chair designed for this study and a conventional chair equipped with backrest. The selected test subjects understood the purpose and intent of this study, and agreed to participate voluntarily. To ensure consistency and accuracy of the comparative evaluation, this study referred to the anthropometric data of Sizekorea (http://sizekorea.kats.go.kr) and selected standard body type Korean males between the ages of 20 to 26, with average (SD) height (173.5cm (±5.5)) and weight (70.4kg (±9.9)). In addition, students with abnormal spine formation which may affect the backrest evaluation were excluded. The Moiré topography photographic instrument (Yagami Model MF-120N) and the scoliometer (Yagami Model YS-1) were applied to screen test subjects with bisymmetric straight spines when seen from behind (Figure 1). Lastly, 310 office workers were asked to directly experience the newly designed chair and then to answer a questionnaire survey so as to collect subjective opinions on the developed prototype.

Figure 1. Moiré topographic photography (left) and scoliometer image (right)

2.2 Research instruments

2.2.1 Development of Spine S-curve Reactive Chair and selection of comparison chair

In developing the Spine S-curve Reactive Backrest, the initial design concept was set to address the problems of the existing chair backrest. That is, despite the fact that spine curvature varies depending on the user, conventional backrests are built with a uniform backrest curve based on equivocal design standards of the manufacturers. The backrest does not conform to the respective spine curvature of the users, and so they are not able to sit their lower backs close to the seat and the lower back is not fully or properly supported by the backrest.

Against this background, an ergonomic approach to maintaining good posture and enhancing users' comfort was taken in developing the chair backrest. Also, the following design criteria were established: minimize sale price by limiting the production cost gap with that of existing office chairs, and thereby facilitate supply to numerous users; produce a backrest that reacts flexibly to the spine S-curve and shift in posture; promote rounded over angulated edges for a contoured backrest that enables the torso to sit comfortably and distribute body weight; and use lightweight and durable backrest frame material, structured simply using few parts, to minimize weight.

Figure 2 shows the chair equipped with the Spine S-curve Backrest developed by this study. Basically, this chair has many of the same parts and features as those of a standard office chair, including a basic seat pan, armrest height adjustment feature, backrest angle adjustment feature, neck support feature, etc. The difference lies with the backrest, which responds in alignment to the user's spine curve and posture movements in order to closely fit and support the lower back when seated, and is geared to maintain the natural spine posture and provide comfort.

In this study discussion will focus on and be limited to the new Spine S-curve Reactive Backrest. The additional adjustment features for an ergonomic chair, such as up-down-left-right adjustment of the armrest, front to back sliding of the seat pan, and synchronized tilting of the seat pan and backrest, will not be dealt with.

The newly designed chair (new design) comprises a seat pan that is the same size and shape as that of a conventional chair, and

Figure 2. The Spine S-curve Reactive Backrest Chair frame (left) and with backrest padding attached (right)

the S-curve Reactive Backrest and backrest padding developed by this study. The top and bottom of the backrest frame are fixed with 15 vertebrae-shaped articulations running down respectively on both sides of the frame, and between them are six flexible articulations designed to respond to the thoracic spine and lumbar curves.

Many of the office chair backrests manufactured and sold locally are not based on solid design criteria. The backrest curve that supports the lumbar (lower back) or back (upper and mid back) are imitations of existing chairs or randomly made to manufacturers' preferences. This study referred to the Ergonomic Chair Recommendations and Requirements (BSR/HFES 100, 2002) when setting the specifications of the new backrest, such as backrest height and width, backrest lumbar support height, backrest width, seat pan-backrest angle and recline range. Particularly, Dowell (1995)'s dimensions were applied in regards to lumbar support, that is, the height and depth of the apex of the lumbar.

The following materials were selected for the new backrest. Nylon glass fiber, which has high tensile force and stability, was chosen for the articulations on the two sides of the backrest to maximize elasticity; and TPR (thermoplastic rubber) was applied for the horizontal torsion bars connected to the articulations to smoothly fit the lower back when the user is seated and enable free curvilinear motion. In other words, each torsion bar and the connected flexible articulation respond and move independently according to the user's spine curvature and motion.

When the backrest of a conventional chair is tilted, the user's lumbar area shifts away from the lumbar support of the chair and loses proper support. However, the new Spine S-curve Reactive Backrest has torsion bars and flexible articulations that respond to the user's lower back motion according to the tilting angle, just as when there was no tilting, and thereby the lumbar area does not shift away and the full lower back including the thoracic spine is supported.

Seen from the side, the S-curve Reactive Backrest maintains and enhances the spine's natural S-curve, and when used for an extended time the backrest serves to maintain good posture and prevent spine deformities. The backrest also conforms to the user's lower back for fitted support, and thus facilitates weight distribution in the lower back area, alleviates stress to the lower back muscles and discs, and ultimately prevents lower back fatigue and pain. After sitting for a long time, the backrest can be tilted so the full lower back sits even more closely to the backrest, a feature designed to support and align the user's spine line and backrest curve. In consequence, the kyphotic curve of the thoracic spine and lordotic curve of the lumbar are supported, providing more comfort and less fatigue in the lower back area.

While the new backrest may be slightly heavier than the existing fixed plastic backrest or mesh-type backrest, the added weight will hardly be noticeable when the chair is used or transported. Furthermore, the padding cover of the backrest itself is of aerial mesh, woven with urethane fiber. This will better circulate the air and keep the temperature from rising around the fitted lower back when the user is seated for extended time, enabling the user to feel more restful.

The conventional chair selected as the comparison target for the newly designed chair equipped with the S-curve Reactive Backrest. In order to minimize differences with the new design, with the exception of the backrest, all other parts have similar dimension, shape and adjustment features.

2.2.2 Measures

As evaluation tools, a motion analyzer (Zebris, 3D Motion Analyzer Type CNS10-6-2) that measures changes in the spine S-curve and an electromyography (BTS, FREEEMG 1000) for reading erector spinae muscle activity (muscle fatigue level) when seated was applied. The JAMAR Goniometer was also used to measure and fix the chair backrest angle when seated. In addition, a follow-up survey of users was conducted with questionnaires after experiencing the new design to collect subjective opinion. Questionnaire items included average daily sitting time, preferred chair style, and post-experience feedback.

2.3 Procedures

All participants were asked to disrobe excluding underpants in order to attach electrodes to the body for measuring the spine S-curve and electromyogram. Testing was conducted under 12 conditions set according to the measurements (spine S-curve and electromyogram), chair types (new design and comparison chair) and chair backrest angles (105°, 115°, 125°). That is, the spine S-curve and para-vertebral muscle activity of the user were measured when seated in each of the two chairs with chair backrest angles set at 105°, 115°, and 125° respectively.

Simple randomization was applied to establish the testing sequence with a randomization list of two chairs and three backrest angles. In order to eliminate any carry-over effect and latent effect, each participant was asked to sit back and relax on a couch ten minutes prior to the start of testing and also five minutes in between the testing sequence. The spine S-curve reading was conducted first, and then the electromyogram analysis was carried out the following day in the same initial testing sequence.

For the purpose of testing, the participants first adjusted the seat pan height so that the angle from the floor to their popliteal height was 90°, and later for the electromyogram analysis, placed both arms on the arm rest once seated and maintained an elbow joint angle of 90°.

2.3.1 Evaluation of spine S-curve using motion analyzer

This study decided on the apices of the cervical spine, thoracic spine, and lumbar as points to attach the electrodes when using the motion analyzer to read changes in the spine S-curve, when seated in the new design and the comparison chair. According to Gelb et al. (1995), the sagittal curvature takes on a normal forms of lordosis in the cervical spine (cervical lordosis), of kyphosis in the thoracic spine (thoracic kyphosis) and of lordosis in the lumbar area (lumbar lordosis). The normal angle range for sagittal curvature is wide and slightly varies depending on gender, age and reader. Generally, the normal range for cervical lordosis is between 25° to 50°, the curvature apex is at the 4th cervical spine (C4) and the vertebral body is at level with the ground. The normal range for thoracic kyphosis is between 20° to 50°, the curvature apex is at the 7th thoracic spine (T7) and the vertebral body is at level with the ground. The normal range for lumbar lordosis is between 20° and 80°, and the curvature apex is at the 3rd lumbar (L3) or intervertebral disc between the 3rd and 4th lumbar. Therefore, as seen in Figure 3, electrodes were attached at

points extended sideways from the three apices (cervical spine C4, thoracic spine T7, lumbar L3). Electrodes should be attached directly to the spine if seeking to purely satisfy the objective of this study, which is to measure changes in the spine S-curve; however, if the electrodes are attached to the spine and the participant is seated, the electrodes become covered by the chair backrest and the ultrasonic signals emitted from the electrodes become undetectable by the ultrasound microphone. As such, electrodes were attached at specifically defined points: thyroid cartilage, inferior angle of the scapula, and the point between the umbilicus and the iliac crest, noted as the body parts corresponding to the apices of each vertebral body (C4, T7, L3). Where the horizontal extensions from these body parts meet with the sagittal gravity line became the defined points to attach the electrodes.

As seen in Figure 3, the participant folded and crossed both lower arms across the chest when seated so as not to cover the three electrodes to be attached. The participant was asked to sit with the lower back closely to the backrest, and look at the target placed in front and at eye level in order to minimize movement.

Figure 3. Measuring the spine S-curve with motion analyzer (Zebris)

2.3.2 Evaluation of muscle activity using electromyography

Surface electromyography (EMG) has been applied in many studies to evaluate erector spinae muscle activity and predict risk level of low-back pain (LBP) (Heydari et al., 2010; Oliver et al., 1996). The EMG evaluation of the erector spinae muscles, in particular, are mainly carried out by attaching electrodes on the surface of L4/L5 or L5/S1, which is the lumbosacral para-vertebral muscle (Rohlmannt et al., 2001). Accordingly, this study also attached four electrodes between the lumbar and sacrum areas, to which pressure is most applied among the vertebrae when seated, as shown in Figure 4, in order to measure para-vertebral muscle activity (fatigue level) using the electromyography (BTS FREEEMG) when seated in the new design chair and the comparison chair. The electrodes were placed to the left and right of the spine: CH1 (left) and CH2 (right) in between lumbar 5 (L5) and sacrum 1 (S1), CH3 (left) and CH4 (right) in between lumbar 4 (L4) and lumbar 5 (L5).

Prior to using the electromyography, the participant was asked to sit with the back and lower back fitted close to the backrest. Any movement of the participant may influence the electromyogram results. Thus, the participant was asked to minimize movement during measurement, keep gaze at eye level, and the tester started the recording of values five minutes after the participant was seated. The participant was also asked to place elbows on the arm rest and clasp both hands together.

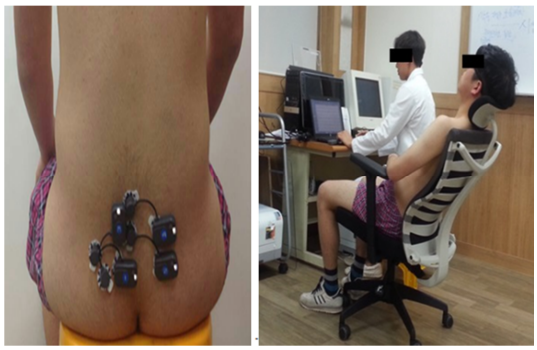

Figure 4. Measuring erector spinae muscle activity with electromyography (BTS FREEEMG)

2.3.3 Subjective opinion

To collect subjective opinion about the new design chair, visits were made to local public offices and office complexes where 310 office workers over the age of 20 were surveyed. Each worker was asked to sit in the new design chair for more than three minutes, freely experiencing the chair in various positions, and then to answer questions about the experience.

The survey asked a total of six questions: age; average daily sitting time; selection criteria for preferred chair (comfort, convenience, health consideration, special features, sturdiness); post-experience feedback (Which part(s) of the body felt comfortable when seated? Did the backrest provide support for the lower back when you change the posture? What advantages did you find with the new design experience?).

2.4 Analysis

Spine S-curve analysis was carried out in reference to the displacement data of the three defined points (C4, T7, L3) for the new design and the comparison chair. To clarify, when the spine is viewed from the lateral position, anterior direction indicates negative number and posterior direction indicates positive number. Analysis was conducted on the average data of the five participants' measurements (motion analyzer applied). Meanwhile, a comparative evaluation was made with the average data of the five participants' measurements of the spine muscle fatigue level (electromyography applied) when seated in the new design and the comparison chair. Lastly, frequency analysis was conducted with the results of the subjective opinion survey on the new design, experienced by the additional 310 subjects.

3. Results

3.1 Spine S-curve evaluation, motion analyzer applied

Table 1 displays the results of the spine S-curve evaluation of the five participants based on the motion analyzer. The table figures refer to the difference between the positions of the comparison chair and the new chair developed by this study (new design). Negative numbers indicate anterior direction while positive numbers indicate posterior direction, and larger figures mean enhanced lordosis of the cervical spine and lumbar, and enhanced kyphosis of the thoracic spine. According to the results, with the backrest angle starting at 105° and as the tilting angle widens, the relative displacement increases for cervical spine and lumbar lordosis and thoracic spine kyphosis.

Table 1. Anterior/posterior position difference of Spine S-curve Reactive Backrest and comparison chair (unit: mm)

Backrest tilting angle	Cervical spine (C4)	Thoracic spine (T7)	Lumbar (L3)
105°	-3.4±116.6	10.3±112.0	-20.5±97.5
115°	-19.1±41.1	23.8±61.5	-39.0±97.0
125°	-25.9±68.0	40.4±65.3	-50.3±96.6

3.2 Fatigue level of para-vertebral muscles, electromyography applied

Table 2 shows an average data for the fatigue level results of the spine muscles based on the electromyography. CH1 (left) and CH2 (right) indicate reading between lumbar 5 (L5) and sacrum 1 (S1), while CH3 (left) and CH4 (right) indicate reading between lumbar 4 (L4) and lumbar 5 (L5). According to the table, larger electromyogram numbers mean higher muscle activity in that body area. Comparing the measurements of the new design and the comparison chair, with the exception of CH3 (shaded areas) with backrest angle at 115°, muscle fatigue level was high when seated in the comparison chair. However, increase in measurements according to backrest angle did not show consistency.

Table 2. Results of Electromyogram (unit: herz)

Backrest tilting angle	Comparison chair				Spine S-curve Reactive Chair			
	L5 btw. S1 (CH1)	L5 btw. S1 (CH2)	L4 btw. L5 (CH3)	L4 btw. L5 (CH4)	L5 btw. S1 (CH1)	L5 btw. S1 (CH2)	L4 btw. L5 (CH3)	L4 btw. L5 (CH4)
105°	145.1±48.5	113.8±42.8	112.8±35.9	128.7±36.8	101.7±34.8	105.8±29.5	72.0±4.9	86.8±31.7
115°	124.2±51.2	99.2±21.5	104.1±34.4	127.4±53.4	99.2±25.3	89.0±37.5	112.1±32.2	120.4±44.3
125°	125.2±33.0	118.2±19.2	143.1±60.3	164.6±24.4	90.9±27.6	99.7±33.7	80.9±16.7	93.5±41.0

3.3 Evaluation of subjective opinion

A subjective questionnaire comprising a total of six items on the Spine S-curve Reactive Backrest Chair was concluded with the following results. Respondents in the 30s and 40s age groups accounted for the lion's share of 67.8%. In detail, 16.1% was in the 20s age group, 32.3% in the 30s age group, 35.5% in the 40s age group and 16.1% in the 50s age group or older. Average daily sitting time of 5~8 hours was the most frequent (45.2%) and 8 hours more was 22.6%, calculated together 67.8% spent 5 hours or more (long periods) seated in chairs. Comfort (83.9%) was the most popular selection criteria for preferred chair, which was exceptionally higher than convenience, health consideration, special features or sturdiness.

The key question of interest was "Which part(s) of the body felt comfortable after experiencing the new backrest design?" The leading answer was "lower back" at 93.5%, "back" accounted for the remaining 6.5% and "head", "neck" and "leg(s)" were not given as answers. To the question "In trying to change position when seated, did the backrest conform to the movements of the upper body and provide support for the back or lower back?" the highest percentage of 87.1% answered positively that "the backrest supports the back and lower back in line with upper body movement"; "the backrest supports the back and lower back, but detaches again upon movement" (6.5%); and "similar to the conventional chair" (6.5%). Finally to the question "What advantages did you find with the new design experience?" answers varied: "It will help with posture correction, and provide comfort and

overcome fatigue" (48.4%), "stable condition" (32.3%), "It will help with fatigue recovery when used for long periods" (9.7%), and "similar to the conventional chair or will have to continue using it before deciding" (8.7%).

4. Discussion

As our living environment becomes more modernized and our work environment changes, the amount of time spent sitting in chairs steadily increases. Computers have already become a necessity both at work and in modern life, and computer usage time has risen drastically, a phenomenon we are all witnesses to. Extended computer usage incurs longer sitting times, and various types of musculoskeletal disorders caused by the interaction between the human body and chair are reported as a result (Shibata and Maeda, 2010).

This study aimed to prevent musculoskeletal disorders caused by such extended sitting times. Test results showed that, when the user leans back on the new backrest design, it conforms to the user's spine line and easily fits the whole lower back in the seat for full support. It is considered that the new design should serve to prevent what typically happens with a conventional office chair, in which the shoulders and thoracic spine area lift away or the lumbar support (of the conventional chair) is pushed away from the back and lower back when the backrest is tilted. As such, as compared to using existing office chairs, the natural spine S-curve was maintained and enhanced with the new design, and it also helped to correct posture, prevent spine deformities and relieve fatigue. These findings correspond significantly with the conditions set by Geyer et al. (2003), in that a chair should promote optimum position adjustment to enable the user to perform functional activities (which is the main objective of sitting), provide stability in sitting position and optimum balance, maintain neutral skeleton alignment, prevent skeletal deformities and tissue weakness, enhance posture comfort, reduce fatigue, and strengthen respiratory and circulatory health.

In order to more fully evaluate the effects of the new backrest design, it is necessary to conduct an evaluation using tools such as the usability test, to directly compare with existing backrests; this, however, is considered realistically difficult. Furthermore, the most accurate way to evaluate the spine S-curve would be to monitor the shape of the spine using an X-ray scanner. Unfortunately, unless you are a medical professional, such equipment is not easily accessible.

According to the results of the spine S-curve evaluation when seated in the new design, starting with the backrest angle at 105° and as the tilting angle widened, lordosis of the cervical spine and lumbar and thoracic kyphosis increased, and thereby improved the spine S-curve. Particularly notable was, with the increase of the backrest tilting angle, the greater displacement gap of the thoracic spine (10.3~40.4) than the cervical spine (-3.4~-25.9), and also that of the lumbar (-20.5~-50.3) more than the thoracic spine. At present, there are relatively few studies that evaluate commercialized or prototype chair backrests as compared to other chair parts. In many cases, regardless, the following studies are referred to as evaluation indices: With reference to spine posture (Bendix et al., 1996; Bishu et al., 1991; Carcone and Keir, 2007; Dolan et al., 1988; Lord et al., 1997; Makhsous et al., 2003; Vergara and Page, 2000b), with reference to body pressure distribution (Dunk and Callaghan, 2005), with reference to electromyogram (EMG) (Dolan et al., 1988; Groenesteijn et al., 2009; Makhsous et al., 2003; van Dieen et al., 2001; Hosea et al., 1986), and with reference to discomfort opinion (Basri and Griffin, 2011; 2013). This study, unlike precedent studies, applied an evaluation method that uses a motion analyzer to measure the spine S-curve changes when the user is seated, thereby making it difficult to directly compare its findings with the results of the aforementioned studies.

Evaluation of the new design using electromyography found that, excluding L4/L5 (left) with backrest angle at 115°, the overall fatigue level of muscles decreased. That is, compared with sitting in the comparison chair, tension in the lower back muscles and pressure on the lower back disc was reduced, thereby preventing fatigue and lower back pain. It is well established that with the increase of the backrest tilting angle from the vertical direction (0°) to 10~30°, the load on the spine disc and para-vertebral muscles is relieved to help prevent lower back pain (Shibata and Maeda, 2010). In particular, Andersson and Ortengren (1974)

reported that muscle activity in the lumbar, thoracic spine and cervical spine areas is reduced up to 110°, while Park et al. (2000) claimed that lumbar disc pressure and back muscle activity decrease the most at 110~130°. In addition, contoured chair back lumbar support maintains lumbar lordosis as well as lowering pressure on lumbar disc L4-L5 (Rohlmannt et al., 2001). The results of this study with reference to backrest angle correspond with the precedent findings at CH1 (L5/S1), but increase/ decrease of measurement at CH2, CH3 and CH4 lacked consistency. Thus, it was difficult to conclude electromyogram change according to backrest tilting angle.

Discomfort scales and questionnaires are generally used to evaluate subjective user opinion of chair backrests (Bishu et al., 1991; Coleman et al., 1998; van Dieen et al., 2001; Vergara and Page, 2000a, 2002). These studies found all positive results for the existence of backrests, and user preference for lumbar support. Similarly, users' subjective preference for the chair backrest developed by this study was also very highly evaluated, and its development is expected to have positive effects on future demand.

5. Conclusion

The Spine S-curve Reactive Backrest Chair (new design) developed in this study responds to the user's spine curvature when seated, and maintains and enhances the lower back's natural S-curve; it thereby promotes better posture, and helps to prevent spine deformities and relieve fatigue more effectively than existing office chairs. This new backrest/chair is designed for persons performing sedentary work or studies, and is applicable not only to adults, but also to high school students or above. There is a need to widely introduce and supply this new design.

Based on the evaluation results collected in this study using the motion analyzer and the electromyography, it is anticipated that the new design will have the following effects on the human body:

1. The Spine S-curve Reactive Backrest is applicable as an office chair or a student chair. Viewed laterally when seated, the spine takes on a natural S-curve, and this curve is maintained and enhanced with the new design. When used for an extended time, it is expected to sustain good spinal posture and help prevent spine deformities.

2. By maintaining and enhancing the natural S-curve of the spine, the Spine S-curve Reactive Backrest Chair should ease tension and pressure in the lower back muscles and discs. Thus, the new design will help prevent fatigue and lower back pain, and improve concentration and work efficiency.

To further verify and generalize the noted effects, long term tracing survey on the aftereffects is suggested as well as usability testing and statistical verification on a number of test subjects. Moreover, durability should be considered prior to commercialization, and further research is needed to easily attach and detach the new backrest design on conventional office chairs.

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