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Multi-position ergonomic computer workstation design to increase comfort of computer work

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A B S T R A C T

This paper presents a new design of computer workstation that is aimed at increasing the comfort of a user working for long periods at a computer. As we have become a society that spends a lot of time working on computers, the computer workstation needs to provide comfort to users. Discomfort and an improper position can negatively affect overall health and productivity. A new type of ergonomic computer workstation, which allows users to sit in multiple working positions, is proposed in order to provide better comfort to people who spend a long time sitting at their workstations. We have designed and developed a new multi-position ergonomic computer workstation which has 19 degrees of freedom and which can accommodate from 5th to 95th percentile human size. Four types of working position (upright, lean-back, zero-gravity and lean-forward) are preset by choosing different angular positions of the workstation parts. Positions of the workstation parts can be changed by controlling the actuators. These four positions were used to evaluate the comfort of the workstation. Subjective and objective evaluations, including comparison of the prototype and standard computer setup, were carried out using human subjects and ergonomic principles. Results showed that the new workstation is much more comfortable, supporting the body in a balanced way. Users have the freedom to stretch and relax in different working positions before they feel any noticeable discomfort; as a result, it lets users work for a longer period without strain, thus resulting in higher productivity.

1. Introduction

Nowadays, the computer is an integral part of our lives. We use computers to do almost every kind of work in our companies and institutions, and even in our homes. When one talks about computer work, the computer chair and desk are the two most important parts after the computer itself. As we have become a society that sits for a greater proportion of the day, it has made the office chair a critical component in determining our overall comfort and health. So, these tools need to provide comfort, since discomfort can negatively affect overall health and productivity, especially for people who work very long hours each day (Karlqvist et al., 2002; Safe Work, 2004).

An uncomfortable computer workspace can cause problems with regard to health and productivity. Discomfort and an improper sitting position for long periods leads to pain around the neck, shoulders, lower back, arms, wrists, legs and other parts of the body. Discomfort also facilitates repetitive strain injury (RSI) in the long term (Andersen et al., 2011; Safe Work, 2004). In 2006, nearly half a million people in the UK suffered from some form of RSI (RSI Awareness, 2011). The productivity of people who work for very long periods each day will be reduced due to the uncomfortable workplace. Moreover, seat discomfort is not limited to computer work, but also distresses aircraft pilots (Goossens et al., 2000), wheelchair users (Chugo et al., 2013; Northwest Regional SCIS, 2004), car drivers and any type of worker that spends a prolonged time in a seated position.

Allie and Kokot (2005) researched the benefits of using an adjustable chair to increase comfort and fix users in a good posture. Supporting workers with high performance chairs positively affects comfort and productivity. So, designing a comfortable office chair which can make posture adjustments in order to maintain comfort was recommended. Bush et al. (1999) measured human movement in the seated position and different chairs in terms of fit, movement and support during changes in recline and spinal curvature to evaluate the performance of office chairs: the performance was different for different chairs. From a different perspective, Robertson et al. (2009) studied the effect of ergonomic training and

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chair intervention on musculoskeletal risk by assigning people to one of three groups: ‘people with training and adjustable chair’, ‘people with training only’ and ‘other people’. The training changed the behavior of people to help them use the office chair properly and decrease musculoskeletal risk. On the other hand, adjustable keyboard and mouse support improved the comfort level of fingers and lower back (Park et al., 2000) while inclination of a keyboard affected the comfort of neck and head (Asundi et al., 2012). Similarly, the impact of different reclined seating postures on typing performance and comfort for people with lower back pain was investigated (Hayanes and Williams, 2008). Different postures had an impact on typing performance, but the authors suggested that further experiments with improved fixtures should be done.

In this research, a new workstation capable of multiple working positions that follows the posture of a user was proposed in order to increase comfort. Thus, the objective of this research was to design a new multi-position ergonomic computer workstation which can support the body in multiple positions to provide better comfort for long periods of work at a computer and, as a result, make a user healthy and productive. The chair and desk were joined by implementing an ergonomic design. Fig. 1 shows the proposed design of the workstation.

2. Design

2.1. Ergonomic design of the workstation

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance (International Ergonomics Association, 2012). The computer workstation interacts with the user; thus, the design of this interaction determines the comfort and performance of the user. The ergonomic design mainly focused on mechanisms for multiple working positions and flexibility of the workstation. Moreover, the shape and form of each part were also considered in the design procedure. The aesthetics and the space occupied by the whole workstation were also taken into account during the design. The workstation was designed to have simple and effective mechanisms that efficiently provide proper comfort to all body parts.

While sitting, people have a tendency to change positions—for example, extending or bending legs, extending or bending arms, leaning back or forward, etc. However, the common standard chair doesn't allow such kinds of position change due to its inflexible design. Nonetheless, users try to change positions as much as possible. This attempt leads to an improper sitting posture, which results in pain. Working at a computer for long periods of time in an improper sitting position can lead to repetitive strain injury (Robertson et al., 2013). Therefore, a new design for a flexible workstation was essential to allow multiple changes in working position.

The layout of the proposed workstation main parts is shown in Fig. 2(a). These parts need to be combined by an ergonomic flexible mechanism. The main parts are the headrest, backrest, armrest, seat, footrest, keyboard and monitor.

All the mechanisms of the workstation were designed separately for each main part. Fig. 2(b) shows assembly of all the mechanisms and skeleton of the workstation. In total, the workstation had 19 degrees of freedom (DOF). The backrest (1DOF), seat (1DOF), footrest (3DOF) and monitor post (2DOF) were driven by

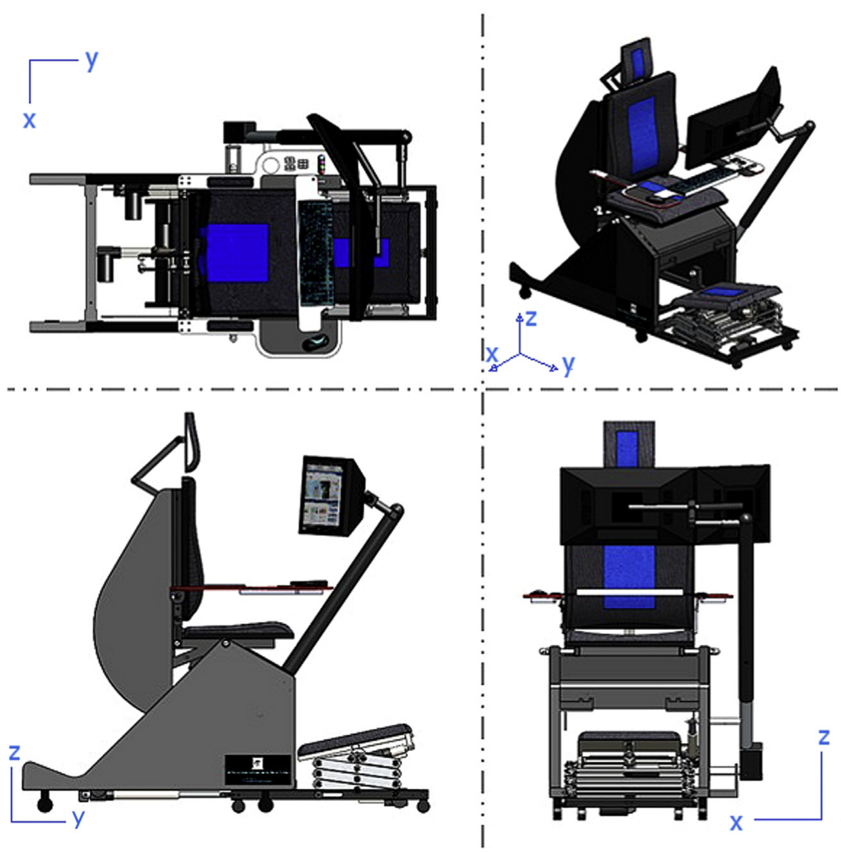


Fig. 1. Proposed workstation design.

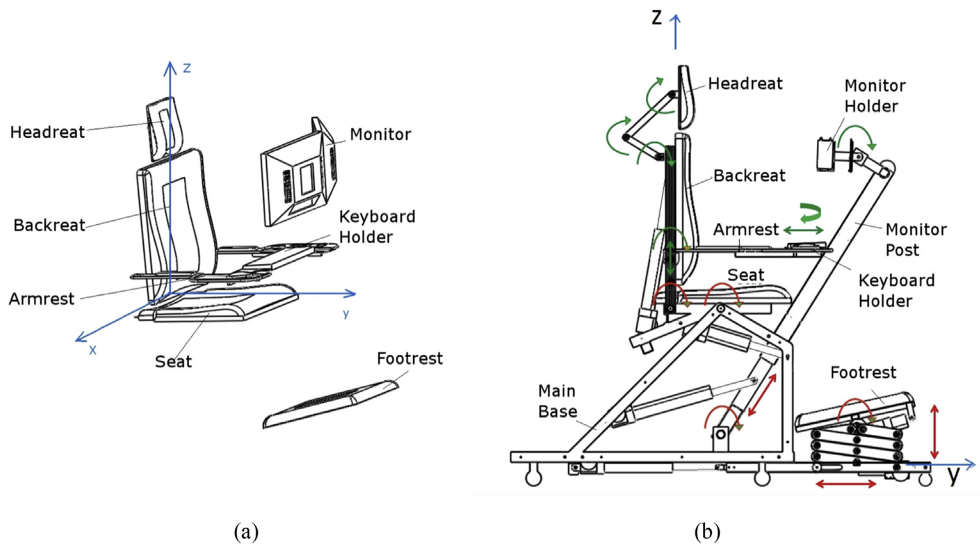


Fig. 2. (a) Layout of main parts and axis convention; (b) Assembly of all mechanisms and DOF.

linear actuators. The headrest (3DOF), armrest (3DOF), keyboard holder (2DOF), monitor holder (1DOF) and main base (whole body) (3DOF) were manually operated.

2.2. Dimensioning

The overall workstation and each part were designed ergonomically so that the workstation could accommodate different sizes of people. The dimensions of each part of the workstation were determined based on the minimum and maximum value of anthropometric data of 5th percentile female and 95th percentile male human size measurements (Federal Aviation Administration, 2009).

In the same manner, anthropometric weight data was used to determine the load applied on the workstation for force and strength analysis. The workstation was designed based on the mass of the upper limit of 95th percentile male user, so that everyone below this would be included (Huston, 2009). So, the workstation could accommodate from 5th percentile female to 95th percentile male human size.

2.3. Kinematics of the workstation mechanisms

The mechanisms of the workstation are actuated and manually operated. Actuated mechanisms are driven by linear actuators. The position and velocity of the moving parts of the workstation directly depends on the position and velocity of the actuator, respectively. On the other hand, the position of the manually operated mechanisms depends on the user action to move the part between the minimum and maximum limits.

Actuated mechanisms of the workstation had 7 DOF. These were the mechanisms of the backrest, seat, monitor post and footrest (as shown by red annotations on Fig. 2(b)). The mechanisms of the backrest, seat, monitor post angle adjustment and footrest angle adjustment are of the same type of mechanisms – the inverted slider-crank mechanism. The mechanism of the footrest height adjustment is a scissors mechanism. The footrest length adjustment and the monitor post height adjustment mechanisms are simple sliding mechanisms. In Fig. 3, the blue lines represent the actuators for inverted slider-crank mechanisms; the red line represents the actuator for scissor mechanism; and the green lines represent the simple sliding mechanisms. The yellow lines represent the driven link, which is the target moving part of the workstation, and the orange lines represent the fixed frame.

Fig. 3. Kinematic analysis of the workstation mechanisms.

Position and velocity equations of these mechanisms were derived to determine the stroke value and the time it took to change from one working position to another.

2.4. Preset working positions

The workstation was designed to have multiple working positions by changing the position of each moving part. It could be adjusted to any position between the upper and lower limits of each moving part. However, four working positions were selected as preset working positions (Fig. 4).

These preset working positions were chosen for their different features and speculated ergonomic advantages as stated below (Graf et al., 1995; Mandal, 2012; Hayanes and Williams, 2008). However, the comfort of these positions was yet to be assessed in the evaluation of the workstation.

1. Upright position: This is a normal position when the spine is vertical. The angles between the torso, thigh and leg are each approximately 90 degrees. It was also used as a reference for the other positions (Fig. 4(a)).

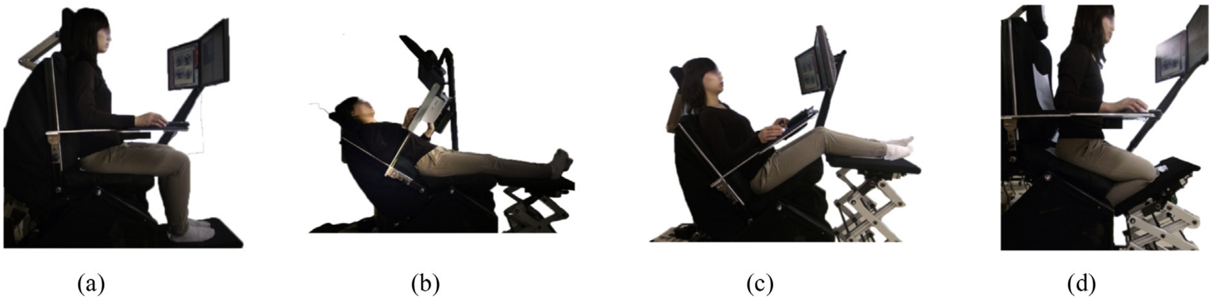


Fig. 4. Preset working positions: (a) upright, (b) lean-back, (c) zero-gravity, (d) lean-forward.

2. Lean-back position: This is a position where a user reclines back from the backrest to a certain designated angle and stretches legs horizontally above the ground. It minimizes stress on the lower back and buttocks by allowing even weight distribution. The spine will be supported following its neutral profile (Fig. 4(b)).
3. Zero-gravity position: This is a position where the user reclines back from the seat to a certain designated angle and stretches legs above the ground to chest level. This position tries to balance the weight by supporting the body at the center of mass so that it feels like there is no gravity (Fig. 4(c)).
4. Lean-forward position: This is a position when a user tilts forward with bent legs. The legs will be supported so as to transfer about 30 percent of the load to the footrest. The back and legs will be relaxed and stretched. It is a modified position of Japanese sitting style called Seiza (Fig 4(d)).

The main driving elements for the change in the workstation positions were the positions of backrest, seat and footrest. The other parts could be adjusted to provide the proper support and configuration. Among the four preset working positions, a user had options to change from current position to one of the other three positions.

3. Evaluation method

A prototype was developed to conduct evaluation in real time. Since the evaluation process included subjective assessment by using human subjects who used the workstation in real time, the prototype was developed in full scale. Fig. 5 shows photographs of the developed prototype.

The main objective of this new workstation design was to give better comfort by supporting the body in multiple positions, which as a result would avoid RSI and make the user more productive. But, comfort is a state and it is a subjective feeling corresponding with positive state, relaxation, free of pain and pleasant experience which depends on the actual user in position (Yang et al., 2009). In spite of different understanding of comfort from different points of view, the methods of evaluating comfort are divided into subjective and objective evaluation methods (De Looze et al., 2003). Thus, the evaluation methods used to evaluate this workstation prototype were both objective and subjective. The objective evaluation was done by comparing standard computer setup and prototype setup using ergonomic parameters. The subjective evaluation was conducted by using questionnaire to rate comfort and discomfort based on personal feelings of test subjects. Two types of subjective evaluation methods were carried out. Global User Comfort (GUC) was used to evaluate comfort of each type of working position separately and Real Time User Comfort (RTUC) was used to evaluate the overall comfort of the prototype workstation. In this paper only the RTUC evaluation is presented.

3.1. Test of the workstation

Before conducting comfort evaluation, a test of the prototype was carried out to assess the design and mechanisms. Test subjects were able to manipulate position of the workstation by controlling positions of the headrest, backrest, seat, armrest, footrest, monitor-post and keyboard-holder. All the mechanisms and control units were functional. Fig. 7 shows the four preset positions captured during test of the workstation. It was observed that the user's back was properly supported following its natural spinal curve, especially on lean-back and zero-gravity positions. Arms, buttocks, thighs, legs and feet were also noticed to be properly supported in

Fig. 5. Prototype of the workstation.

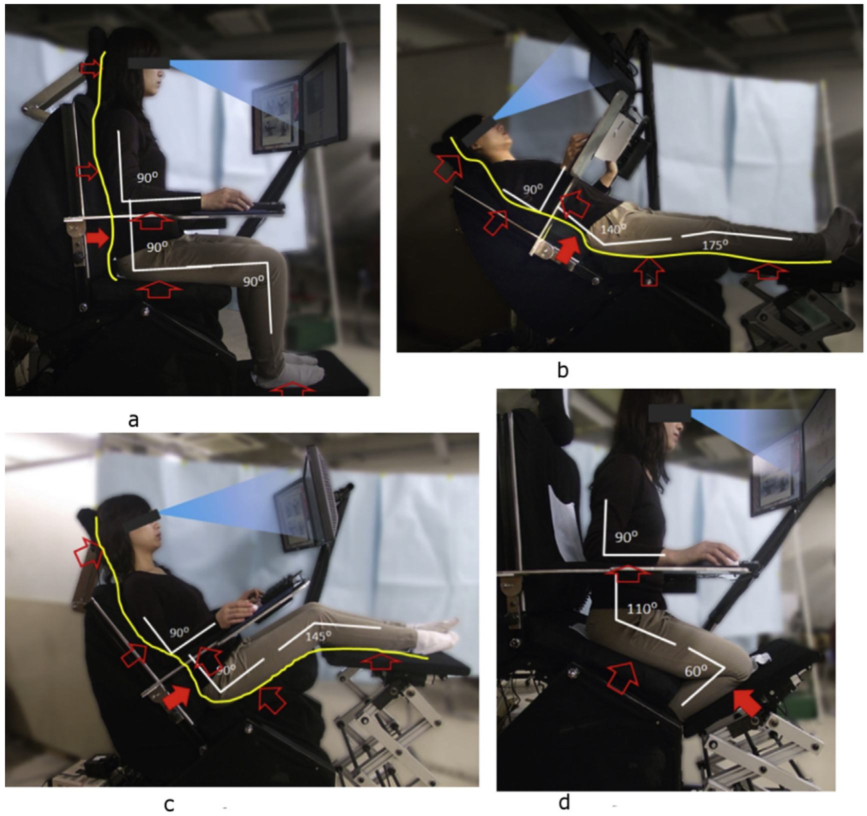


Fig. 6. Test of the prototype in four preset positions (a) upright, (b) lean-back, (c) zero-gravity, (d) lean-forward.

all positions. The monitor could be adjusted at ergonomically advised position for all kinds of position as shown by the blue gradient. The angles on Fig. 6 show the approximate values for each type of preset positions. The arrows show the main contact points where the body was supported, whereas the yellow lines emphasize how the body was supported.

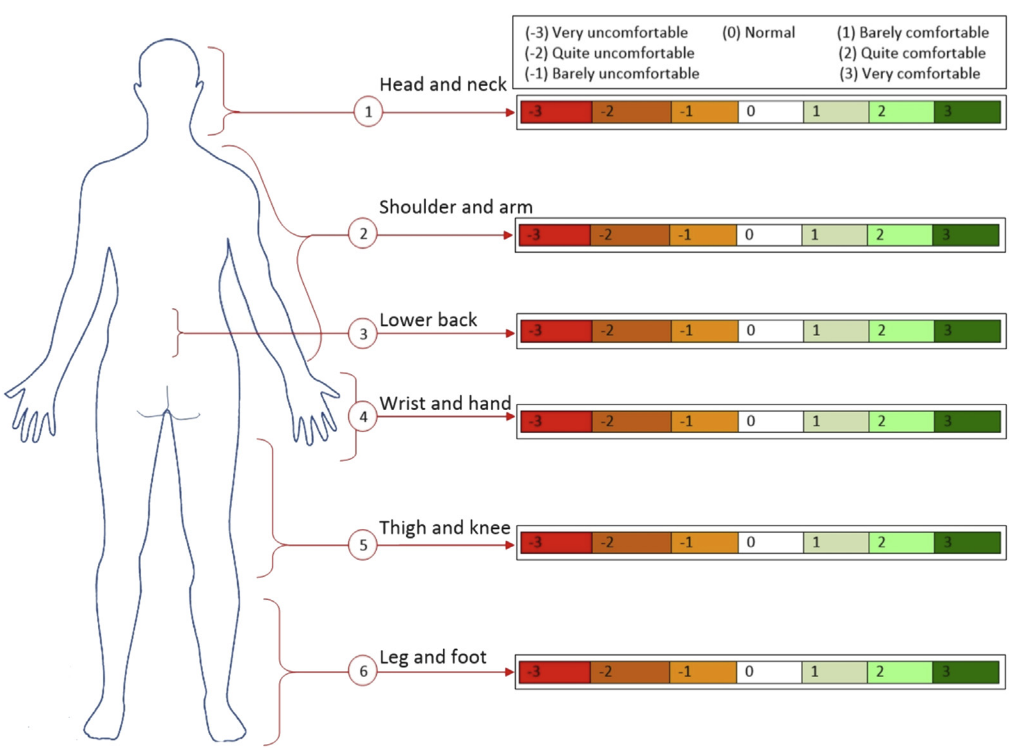
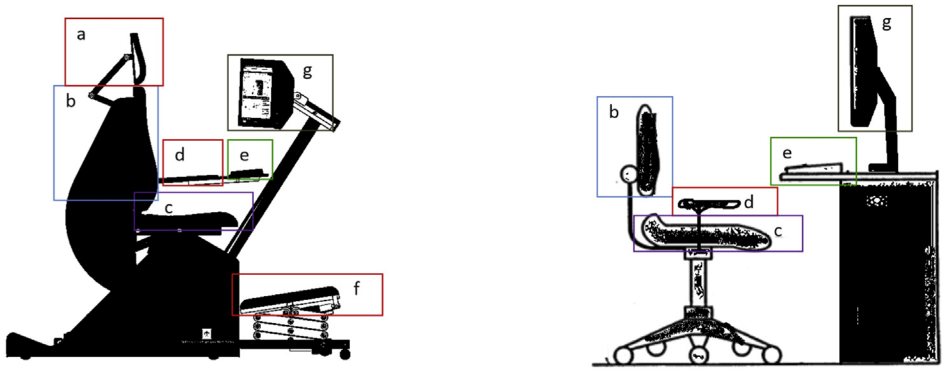


Fig. 7. Questionnaire of RTUC evaluation.



(i) Prototype (ii) Standard

Key: (a) Headrest, (b) Backrest, (c) Seat, (d) Armrest, (e) Keyboard and Mouse, (f) Footrest and (g) Monitor

Fig. 8. Prototype workstation and standard PC workstation setups.

3.2. *Real Time User Comfort (RTUC) evaluation*

RTUC is a subjective evaluation method. In this evaluation, a subject used the prototype workstation as if it were his/her own personal computer workstation. Participants were instructed to perform their own tasks freely, as they would do at their own personal computer, for two continuous hours to make the experience as real as possible. They were also advised to change working positions from one preset position to another as necessary. Subjects already knew how to change the position of the prototype workstation since they had performed prior tests. After completion, participants rated their comfort on a questionnaire (see Section 3.2.1). Subjects also performed the same tasks using a standard setup and rated their comfort on the same questionnaire. Results of the prototype were compared against the results of the standard setup to see the difference.

The evaluation was carried out by recruiting 14 human subjects (nine male and five female). Attempts were made to include a mixture of participants of different gender, age, size and nationality (age: 28 ± 6 years, body mass: 62.5 ± 12.5 kg, height: 166 ± 16 cm). Preference was also given to people who spent longer periods of time working at computers. All participants were mentally and physically healthy, with a normal body mass index (BMI). Evaluation procedures used in this research were reviewed by our institute's Institutional Review Board. The procedures were explained and all participants provided written informed consent prior to testing.

3.2.1. *Questionnaire*

The questionnaire for RTUC evaluation was developed by merging and modifying other subjective methods (Li and Buckle, 1999; Karwowski and Marras, 2003). It has three sections and a personal comment/suggestion textbox at the end.

In the first section of the questionnaire, a human body outline that indicated six general body parts was presented. Each body part was associated with a comfort scale (Fig. 7). The second section had three questions about comfort of keyboard, mouse and monitor. The comfort scale had 6 levels. These levels were very uncomfortable, quite uncomfortable, barely uncomfortable, normal, barely comfortable, quite comfortable and very comfortable (corresponding numbers were −3, −2, −1, 0, 1, 2 and 3, respectively). The baseline for comfort was “normal (0)” scale. The third section asked to rate the overall comfort of the prototype setup against the standard setup (the overall comfort of the standard setup was considered “normal”). Fig. 8 shows the prototype and standard setups highlighting the main parts and design differences.

4. Results and discussion

The questionnaire results for both workstation setups were

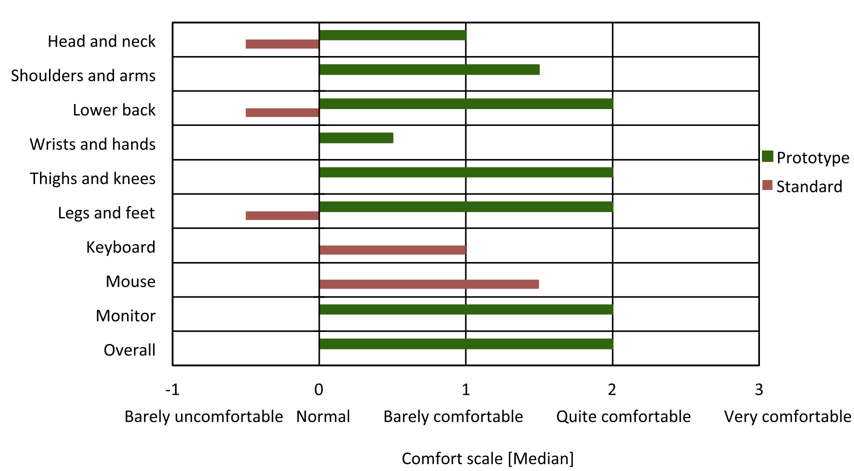


Fig. 9. RTUC evaluation results of prototype and standard setups.

Table 1
Pairwise comparison of comfort of body parts (the different in mean comfort values of body parts based on prototype setup, (row) − (column)).

Body parts (mean)	Shoulders and arms (1.21)	Lower back (1.57)	Thighs and knees (2.14)	Legs and feet (2.14)
Head and neck (0.86)	0.36	0.71	1.29	1.29
Shoulders and arms (1.21)		0.36	0.93	0.93
Lower back (1.57)			0.57	0.57
Thighs and knees (2.14)				0.00

collected from all participants. Results for the two setups were collected separately. The median values of comfort scale data for each part were calculated for both setups. Fig. 9 shows the summary of comfort scale (median value) of each part for both prototype and standard setups. In Fig. 9, the first six items on the vertical axis are body parts and the other three items are workstation parts.

A within-subjects repeated measures analysis was conducted to verify the statistical significance of the results. A test of within-subjects effects revealed that there was a significant impact on comfort of each body part based on the workstation setup. There was a significant change in comfort of the head and neck due to workstation setup, $F(1,26) = 11.927$, $p < 0.05$. Similarly, a significant change in comfort value of the legs and feet was shown due to workstation setup, $F(1,26) = 43.513$, $p < 0.05$. However, no significant effect due to workstation setup was indicated in comfort of wrist and hand, $F(1,26) = 0.89$, $p > 0.05$. A pairwise comparison of the mean comfort values by body parts revealed that lower body comfort was rated significantly better than the upper body parts on the prototype. The differences in mean comfort values between the significantly different body parts based on the prototype setup are listed in Table 1.

Participants performed their own personal work as they would do on their personal workstation. Participants were noticed to be changing working positions frequently which was in every 20 min, on average. Since testing of the prototype was carried out prior to this evaluation procedure, participants were able to change and control positions without difficulty.

Results showed that there was no discomfort during working on the prototype workstation; comfort scales for all parts were above the "normal" comfort scale (comfort scale ≥ 0). On the other hand, half of body parts (head, neck, lower back, legs and feet) exhibited discomfort (comfort scale < 0) during working on the standard setup. The headrest and armrests of the prototype improved comfort of the head, neck, shoulders and arms (comfort scale ≥ 1). The results of the lower back comfort (comfort scale $= 2$) indicated that the backrest of the prototype provided great comfort for the lower back, which is usually the sensitive area to feel pain during computer work. Lower body parts (thighs, knees, legs and feet) experienced high comfort (comfort scale $= 2$) during working on the prototype. In another evaluation of comfort of the prototype parts, the footrest registered the highest comfort value. It shows the consistency of results. The footrest created big difference in the comfort of lower parts of the body. The monitor was also comfortable (comfort scale $= 2$) and better than the standard setup due to its adjustability to a convenient distance from the eyes. This result may also be associated with the behavior in using dual screens (Szeto et al., 2014).

The keyboard and mouse of the prototype were "normal" (comfort scale $= 0$), but not more comfortable than the standard setup (comfort scale ≥ 1). Even though the users could choose their own comfortable position to get better comfort from possible position configurations, largely reclined positions were comparatively less comfortable for mouse and keyboard use. It was observed that the mouse pad area was small which decreased the comfort of mouse. The keyboard holder was also not big enough to support wrists while typing. It was also speculated that the type of keyboard and mouse used for evaluation might have affected the result since every participant used different keyboard and mouse at his/her own PC.

Participants were asked to rate the overall comfort of the prototype setup against the standard setup by assuming the standard setup as "normal" (comfort scale $= 0$). All participants rated the overall comfort of the prototype workstation as "quite comfortable" (comfort scale $= 2$). Also the participants were asked to choose which setup they prefer to use for working at computer, and all participants chose the prototype workstation.

4.1. Comfort of parts of the prototype workstation

Participants were asked to rate the comfort of parts of the

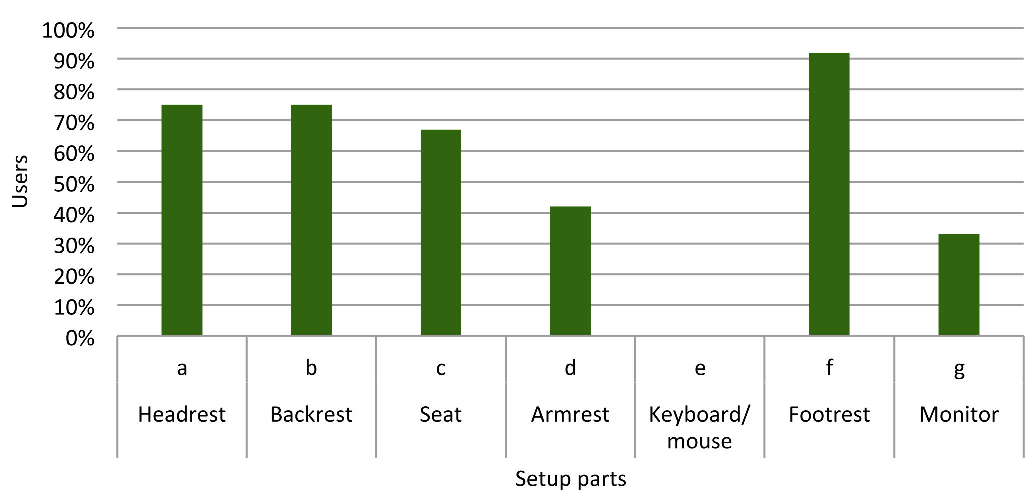


Fig. 10. Comfort of different parts of the prototype (0% is baseline for comfort of parts of standard setup).

Table 2
Chi-Square results of each workstation part.

Workstation parts	Headrest	Backrest	Seat	Armrest	Keyboard/Mouse	Footrest	Monitor
X^2 value	18.118	18.118	15.556	9.333	1.037	24.2667	7.636
p-value	<0.001	<0.001	<0.001	<0.01	>0.1	<0.001	<0.01

prototype by taking the standard computer workstation setup as a baseline for normal comfort. Workstation parts were divided into seven parts for comparison (Fig. 8). Participants selected the parts of the prototype workstation that made them comfortable. The summary of the results is shown in Fig. 10. The vertical axis shows the number of users in each percentage. The data were analyzed by using a chi-square test for each workstation part. The test revealed that the results for all parts, except for the keyboard/mouse, were statistically significant, $p < 0.05$. No significant difference was found for the keyboard/mouse, $p > 0.1$. Table 2 shows the values of the chi-square test for each part. The headrest, backrest and footrest were significantly comfortable among the other parts. 91.7% of participants identified that the footrest increased their comfort during computer work. This indicates that the new design of footrest was the most prominent in increasing comfort. Each part made its own contribution to the overall comfort. The keyboard and mouse were not selected, as these two parts did not show improved comfort during the RTUC evaluation.

5. Conclusions

A full-scale prototype of the "Multi-Position Ergonomic Computer Workstation", which had 19 degrees of freedom and could accommodate from 5th percentile female to 95th percentile male human size, was designed and developed. Changing the working positions of the prototype was easy to learn. The results from the RTUC evaluation indicate that the new design can improve the comfort of computer work by supporting the user's body in a balanced way in any working position. Changing the working position allowed the body parts to stretch and relax before pain developed. As a result, a user may work for longer periods of time without pain, increasing productivity and lessening the risk of RSI. The mechanism of the footrest provided better comfort for the lower body parts, which implies that a flexible footrest is important to improve the overall comfort of seated computer work. The idea of combining the chair and desk was convenient to the design of ergonomically effective mechanisms. The proposed design promises to increase comfort; however, the design of keyboard holder and armrest should be improved to allow more space for the keyboard and mouse. Further evaluations should be conducted by using subjects in different body mass index (BMI) categories.

5.1. Future work

In this research, changing a working position was based on a user's personal feeling; a user didn't know for sure if the new position he/she changed into was the best position that would eliminate a previous discomfort. In the future work, pressure sensors will be introduced to measure and monitor the pressure distribution around sensitive body parts. If there is a high pressure area, non-uniform distribution or hot spot, it may create fatigue in the body that can lead to discomfort over time. We plan to develop a system that intends to determine and recommend a different working position to eliminate a current hot spot based on the pressure distribution mapping. Minor design modifications will also be made to improve the uncomfortable workstation parts.

Acknowledgments

The authors would like to thank all the participants in the evaluation process, with a special thank to the girl portrayed in the images.

Appendix. Control of actuators

The linear actuators were bought directly from the market after a selection based on the required parameters. The manufacturer is Wuxi JDR Automation Equipment Co., LTD, China. The manufacturer provided its own control box and control switch handset. The given parameters of actuators are shown in Table 1. In total, there were eight actuators and two sets of control boxes. The first set controls five actuators and the second set controls the other three actuators. For assembly and appearance purpose, a new control panel was designed to replace the handsets. It was assembled on the left armrest for ease of access (equivalent to mouse location on right armrest).

Table 1
Parameters of the actuators.

Input voltage	24 V DC
Max. load capacity	6000N (4 mm/s)
Max. speed	30 mm/s (750N)
Stroke	50–600 mm
Min. install dimension	Stroke + 175 mm
Limit switches	Inner
Type of duty	S2 – 10 min
Operation temperature	−26 °C – 65 °C
Protection class	IP43

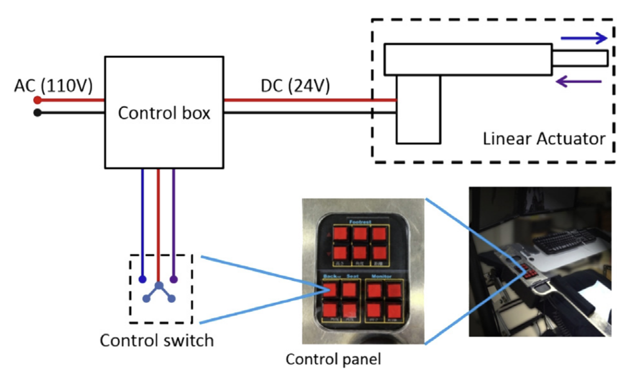


Fig. 1. Schematic of actuator control system.

The control box had an input AC voltage of 110 V and 12 V DC voltage of output to power the actuator. The actuator and the control switch were connected to the control box. The control switch has two switches for extension and retraction motion of each actuator as shown in Fig. 1. Each actuator has its own control switches on the control panel; so, the actuators were controlled separately.

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