

SEAT POSITION AND CONTOURS FOR HIGH SCHOOL CHAIRS

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Synopsis

School chairs present several particular design difficulties. The need for low cost and durability dictate the use of a firm, non-adjustable chair. The design of a chair to provide the best fit for a population is not simply a matter of fitting the average size person from the population. The appropriate dimensions of a chair to provide the best fit for a population can be determined by ensuring that ‘the smallest can fit and the largest can reach.’ Just as the anthropometric dimension of an average size person is not necessarily the appropriate dimension to use for determining a dimension of a chair for that population, so too the angles and contours suitable for an average size person are not necessarily the most suitable for the population as a whole. Unfortunately clear principles that enable fitting the dimensions of a chair to a population do not appear to exist for fitting the angles and contours of a chair to a population, particularly a school population.

An understanding of the mechanics of sitting is a prerequisite to addressing the question of fitting a chair to a population. Chapter 2 presents a qualitative discussion of the mechanics of the interaction between a chair and its occupant. In addition to the commonly considered chair design features such as the heights and angles of the seat and backrest the contour of the seat is also shown to be an important element in the overall functioning of a chair.

The purpose of the experiments described in Chapter 3 are to determine the appropriate seat position for the largest size school chair in Australian schools. An experimental chair was constructed with the height of the front of the seat, seat depth, and seat width as described by Sebel Furniture (1995) and Australian Standards (1995). The experiments in Chapter 3 consisted of two groups of 16 Year 11 students adjusting the rear seat height (seat angle) on an experimental chair to their preferred height. The first group adjusted the rear seat height during a simulated classroom activity while sitting at a desk as used in their usual classroom. As the results from this group suggested that the desk height could have influenced the preferred rear

seat height a second group adjusted the rear seat height for a brief adjustment period while sitting at three different desk heights. The results indicate that there were no significant differences between the long and short adjustment periods and that the seat angle corresponding to the preferred rear seat height was between -1.1 to $+2.7$ degrees. The preferred rear seat height of students exhibited a negative correlation with their popliteal height and a positive correlation with the height of the desk being used at the time. In other words students with a higher popliteal height preferred a lower rear seat height and when a higher desk was used, the students preferred a higher rear seat height.

In Chapter 4 a second experimental chair with a purpose built contour measuring device (bumograph) mounted in place of the seat was used to measure seated buttock contours. The position of the bumograph corresponded with the seat position determined in Chapter 3. The buttock contours of 16 Year 11 students were measured while sitting on the experimental chair in a range of postures used in the school setting. One anterior-posterior (AP) and one lateral profile were extracted from the measured contours and six dimensions from these profiles were analysed for common features and systematic variations related to posture, mass, or gender which may assist in the design of future school chair seats. The data showed consistent patterns in the general shape of both the AP and lateral profiles. Five out of the six profile dimensions were significantly different for males and females. In contrast only one dimension for one pair of postures demonstrated significant differences.

A synthesis of the theoretical and experimental work from Chapters 2-4 is presented in Chapter 5. Particular attention is given to how the findings of the present studies may be applied to future research and to school chair design.

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This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

Signature

Date

1

Introduction

“The most universal physical occupation of civilised human beings is sitting” (Bennett, 1928)

Background

Sitting and chair design

Sitting is well suited to the performance of fine motor or perceptual tasks by providing an upright posture of the head and trunk while allowing free movement of the arms and hands combined with greater stability and less effort than is necessary in standing postures. Sitting however is considered to be potentially damaging to the extent that 'correct seating is a contradiction in itself' (Erns, 1992). The very stability that makes sitting useful creates a tendency towards immobility with its potential to adversely affect the musculoskeletal system.

One method of attempting to reduce the adverse effects of sitting is to ensure that the chair fits the user (Shackel, Chidsey, & Shipley, 1976). Chair dimensions can be related to one dimensional anthropometric measurements. For example, the height of the front of the seat can be determined from the user's popliteal height; the seat width between armrests can be determined by the width of the user's hips, the seat depth can be determined by the user's corresponding anthropometric measurements.

Fitting a population rather than an individual, however is much more complex (Melzer & Moffitt, 1996). If the seat width and seat height of an armchair were made to fit the average dimensions of a population, the chair would be unsuitable for most of the population. Users with shorter than average popliteal heights would be unable to reach their feet to the floor and users with a larger than average pelvic width would be unable to fit between the armrests. Designers frequently aim to accommodate 95% of the population by following the principle to design such that the largest can fit and the smallest can reach (Pheasant, 1992). Applying this principle to the above example would result in an armchair with the front of the seat at the height of the 5th percentile popliteal height and the seat width able to accommodate the 95th percentile pelvic width (Zacharkow, 1988). Although this chair would be unlikely to exactly fit any one

individual, it would be usable by a far greater percentage of the population than if the average dimensions were used (Pheasant, 1992).

Although anthropometric data can be useful in the determination of appropriate dimensions of a chair, such data cannot determine other aspects of chair design such as the angles and relative positions or the contours of the seat and backrest. The angles of the seat and backrest are not specific to an individual, but are related to the postures used for the tasks to be performed (Lueder, 1994). For example, a tractor seat may suit an individual driving a tractor, but is not suitable even for the same individual attending the theatre. A chair may function very well for having one's hair washed, but be totally unusable for operating an industrial sewing machine. It is thus insufficient to discuss what constitutes a suitable chair without reference to the activities to be performed in the chair as well as the user or users.

There is limited agreement on the solutions to the problems associated with seating even when considering a single activity such as keyboard work. Recommended seat heights for a particular individual vary by up to 15 cm (Mandal, 1994). Recommended seat angles for a workstation chair vary by at least 50 degrees and recommended backrest angles by at least 20 degrees (Zacharkow, 1988). Numerous variations of seat contours (Bennett, 1928) and backrest contours (Lueder et al., 1994) have been recommended and the recommended backrest position varies from the level of the sacrum to the mid thoracic spine (Zacharkow, 1998).

One means of enabling a chair to suit not only a range of users, but also a range of postures or activities is to make elements of the chair adjustable. The angle, height and relative positions of the seat, backrest and sometimes even the armrests are thus made adjustable on many current model chairs (Lueder, 1994).

School chairs

School chairs present several design challenges not present in chairs for an adult or office population. Even though students of different sizes use a particular school chair the need for low cost, durable and often stackable chairs generally precludes the use of adjustable chairs (Australian Standards, 1995). Instead a limited number of sizes of school chair are produced often resulting in one size being used for more than one Year of students. Six chair sizes are produced for Australian schools, one for each pair of years 1-2, 3-4, 5-6, 7-8, 9-10, and 11-12 (Australian Standards, 1995). The anthropometric dimensions of student populations using each size school chair in Australia are well documented. The dimensions such as the height of the front of the seat, seat depth, and seat width of each size of school chair can thus be determined which enable that size chair to achieve the best fit for the target age group (Australian Standards, 1995; Sebel Furniture, 1995).

The design of suitable school chairs is complicated by the facts that not only do students of different sizes use a single size chair, but school work involves a variety of tasks and a variety of postures. For example students might sit forward when writing and sit back when attending to instruction from the front of the classroom (Yeats, 1997). Each size of non-adjustable school chair thus needs to accommodate not only a range of student sizes, but also a range of postures.

The principles that apply to adult seating cannot necessarily be applied directly to school seating. Even though there is little agreement about the configuration of appropriate seating for adults, the theories applying to adults are often assumed to apply equally to seating for children (Sebel Furniture, 1995). The physical proportions and muscular development are different not only between adults and children, but also between children of different ages (Zacharkow, 1988). Thus an appropriate chair for one age group of children would not necessarily result from simply scaling down an adult chair or even from proportionate scaling of another size of school chair.

It was therefore considered necessary to examine aspects of school chair design such as angles, relative positions and contours of the seat and backrest which cannot be determined from anthropometric data. The current study begins the examination of school chair design by determining experimentally the appropriate seat position for the largest size of school chair in Australian schools and continues by measuring seat contours of students sitting on a seat in the experimentally determined position. It is envisaged that future studies will use the contour data obtained in the current study to develop an improved seat contour for school chairs. Further research applying a similar method to that used in the current study in relation to seat position and contour will investigate backrest position and contour culminating in a school chair design based on experimental data rather than unfounded assumptions.

Outline of current study

This thesis consists of three papers related to school seating brought together in the subsequent chapters.

Chapter 2 presents a qualitative discussion of the mechanics of the interaction between a chair and its occupant. It is considered that the more muscular effort necessary for a user to sustain a particular posture in a chair, the less desirable that chair is for the user in that posture. The effects and interrelationships of various features of chair design on forces acting on the occupant are discussed. In addition to the features of chair design which are most commonly considered such as the heights and angles of the seat and backrest, the contour of the seat is also shown to be an important element in the overall functioning of a chair.

The purpose of the experiments described in Chapter 3 are to determine the appropriate seat position for the largest size school chair in Australian schools. The height of the front of the seat, seat depth, and seat width described by Sebel Furniture (1995) and Australian Standards (1995) were considered to be appropriate for the target population. The preference of the users was considered a valid assessment tool for the current study as it has been previously shown to be an accurate method for students assessing school chairs (Kroemer, 1994).

The experiments in Chapter 3 consisted of two groups of 16 Year 11 students adjusting an experimental chair. The experimental chair consisted of a seat and backrest from a commercial school chair. The front of the experimental chair was set to the height recommended by Sebel Furniture (1995) and Australian Standards (1995). The height of the rear of the seat (the seat angle) of the experimental chair was adjusted by two groups of 16 Year 11 students to their preferred position. The first group adjusted the height of the rear of the seat to the position they would prefer for doing the variety of tasks normally performed in the classroom while sitting at a desk as used in their usual classroom. As the results from the first group suggested that the desk height could have influenced the preferred rear seat height a second group of students

adjusted the rear seat height on the experimental chair while sitting at three desks of different heights.

A second experimental chair with a purpose built contour measuring device (bumograph) mounted in place of the seat was used in the experiment described in Chapter 4. The position of the bumograph corresponded with the seat position determined in Chapter 3. The buttock contours of 16 Year 11 students were measured while sitting on the experimental chair in a range of postures used in the school setting. The measured contours were analysed for common features and systematic variations related to posture, mass, or gender.

A synthesis of the theoretical and experimental work from Chapters 2-4 is presented in Chapter 5. Particular attention is given to how the findings of the present studies may be applied to future research and to school chair design.

2

Biomechanical influences on lumbar posture in sitting

Ideally a chair accommodates the body in a range of postures appropriate to the chair's function. A chair design is considered desirable if it minimises the net torques acting on the pelvis thereby minimising the sustained muscular effort necessary for maintaining a posture. A 4-link model of the seated human body in the sagittal plane is described. The effect of factors in chair design including the positions of the seat and backrest, the angles of the hips, knees, and lumbar spine, and the contour of the seat on torques acting on the pelvis are discussed. An example is presented whereby three school chair designs are evaluated showing the effects of each chair's design features on torques acting on the pelvis.

Introduction

Compared with standing, sitting requires less effort, reduces load borne by the legs, places fewer demands on the circulatory system, and provides greater stability (Grandjean & Hunting, 1977). Standing is an inherently unstable position, characterised by a relatively high centre of gravity located over a relatively small base of support. Muscular effort is therefore needed to maintain the stability necessary for fine motor control or repeated tasks in standing (Zacharkow, 1988). These tasks can be performed more accurately and with less effort from a posture providing a greater degree of stability such as sitting. When compared with lying, however, sitting requires more effort and is less stable. Sitting does not merely reduce effort and increase stability, but is a means of providing a balance between the conflicting requirements of stability and mobility (Festervoll, 1994).

There has been considerable debate about what the “best” posture is when sitting on a chair or stool. The traditional right angle posture (Fig. 2.1a) with the trunk upright, the feet flat on the floor and the hips, knees and ankles at 90 degrees has long been advocated as the correct sitting posture (Hemmings & Hemmings, 1989). Mandal (1981) suggested that few people are able to sustain this position for more than a few minutes and instead proposed a posture with the thighs inclined by up to 45 degrees to facilitate the trunk being upright or inclined forward without reducing the lumbar lordosis (Fig. 2.1b). Alternatively, Grandjean and Hunting (1977) recommended a semi-reclined posture (Fig. 2.1c) with the seat reclined by up to 14 degrees to minimise disc pressure and muscular effort. The above authors applied different criteria to different functions performed in sitting and, not surprisingly recommended different postures. Appropriate postures vary with the population and the functions performed in sitting. For example, an adult working at an industrial sewing machine (Yu & Keyserling, 1989) does not have the same requirements as a primary school student (Sebel Furniture, 1995). An appropriate chair must thus be able to accommodate the needs of the users and support the postures necessary for the particular tasks to be performed. Even if the requirements of the users and

tasks can be adequately addressed, there are other potential problems associated with sitting.

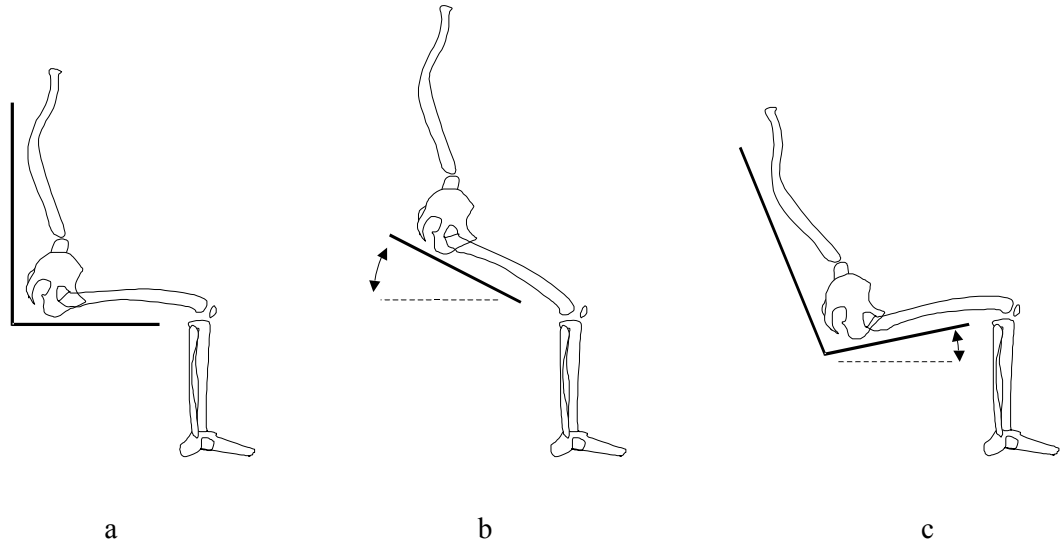


Figure 2.1 Proposed sitting postures. a). Traditional cubist posture with trunk upright, and the hips, knees, and ankles at 90 degrees (Hemmings & Hemmings 1989). b). Forward posture with seat inclined by up to 45 degrees (Mandal, 1984). c) Semi-reclined posture with the seat reclined by up to 14 degrees (Grandjean & Hunting, 1977).

The effects of sustained postures, static muscle contractions and reduction of the normal spinal curvatures are the main factors blamed for the adverse musculoskeletal effects associated with sitting (Bendix, 1994). It is often stated that static postures reduce the nutrient supply to the muscles, joints, discs and connective tissue. As increased stability is one of the main reasons for adopting a sitting posture, static postures are, to some extent, inherent in sitting. Chair designs can reduce, but not eliminate static postures by supporting the widest possible variety of postures through their shape, adjustability and flexibility (Suzuki, Sugano, and Kato, 1994). Work practices can also reduce static loads by introducing task and postural variation (Festervoll, 1994).

Stability however does not necessarily require static muscle contractions. A stable, balanced posture may only require intermittent muscle contractions for postural adjustments (Cranz, 1998). Sustained muscle contractions are necessary to maintain a position when the sum of forces and torques from non-muscular factors do not equal zero. For example, leaning back in sitting without a backrest requires sustained muscle contractions if the position is to be maintained. The greater the net forces or torques acting on the body to move it from the required or desired position, the greater the muscular effort necessary to maintain the position.

Zacharkow (1988) considered the relaxed, non-weight-bearing position as occurs in sidelying or when weightless to represent normal spinal curvature. McKenzie (1981) however considered the more pronounced lordosis present in standing to be the normal curvature. Regardless of which of these postures is considered as normal, the forces created in sitting tend to reduce or even reverse the lumbar lordosis (Bridger, Von Eisnehart-Rothe and Henneberg, 1989; Black, McClure and Polansky, 1996). This lumbar flexion is associated with increased lumbar disc pressure (Andersson, Ortengren, Nachemson and Elfstrom, 1974), increased lumbar pain in symptomatic subjects (McKenzie, 1981), altered cervical postures, and headaches (Winkel & Westgaard, 1992).

Chair designs employ a variety of strategies and mechanisms to reduce the net forces acting on the body tending to alter the 'normal' spinal posture. Greater net passive forces (as opposed to active or muscular forces) acting to alter normal spinal postures result in either a greater tendency for the spinal curvature to change or increased muscular contractions to maintain a normal posture. This paper will consider how to minimise the net magnitude of these passive forces that occur between the user and their chair.

The specific needs and attributes of the users give rise to a multitude of factors that affect chair selection. For example, the flexibility (Bridger, Wilkinson and van Houweninge, 1989) and the skill (Cranz, 1998) of the user greatly affect the degree of effort necessary to maintain a particular posture. The dimensions of chairs should suit the anthropometric characteristics of the

users. Criteria for ensuring a good dimensional fit are discussed in various texts on seating (Zacharkow, 1988; Pheasant, 1992; Lueder & Noro, 1994) and will not be duplicated here. The properties of the seat surface which can fail to provide sufficient stability by being too soft or can be uncomfortable by being too hard or inappropriately shaped (Zacharkow, 1988) will also not be discussed. In addition, seating is more than simply a matter of comfort and mechanics. Historically as well as in the modern office, status and personal image are communicated by chairs more than by any other aspect of office design or furniture (Cranz, 1998).

The purposes of this paper are:

1. To provide a summary of biomechanical influences for assessing the effect of chair design features on spinal postures in sitting.
2. To demonstrate how these biomechanical influences can be used to evaluate chair design features through a relevant practical example.

Specifically, the forces acting on the pelvis that influence spinal curvature are identified, categorised and used as a means of evaluating three school chair designs. It is foreseen that this framework, when combined with knowledge of the needs of the user will assist with appropriate chair selection.

Postures of the spine and pelvis

Serber (1994) and Goossens and Snijders (1995) describe similar symmetrical models of the seated body in the sagittal plane consisting of four links ie shank and foot, thigh, pelvis, and trunk (Fig. 2.1a). The three joints between the links being the knee, hip, and the centre of rotation of the lumbar spine, ie the body of the third lumbar vertebra (Serber, 1994). The angle formed at L3 between the pelvis and the trunk has been shown to be an accurate indicator of the degree of curvature of the lumbar spine (Delisle, Gagnon and Sicard, 1977; Black et al., 1996; Levine & Whittle 1996). Relative to the neutral position shown in Figure 2.2a, posterior rotation of the pelvis flexes the lumbar spine decreasing or reversing the angle of the lumbar lordosis (Fig. 2.2b). When the pelvis rotates anteriorly in relation to the trunk, the lumbar spine is extended increasing the lumbar lordosis (Chaffin & Andersson, 1984; Delisle et al., 1977; Yasukouchi & Isayama, 1995) (Fig. 2.2c).

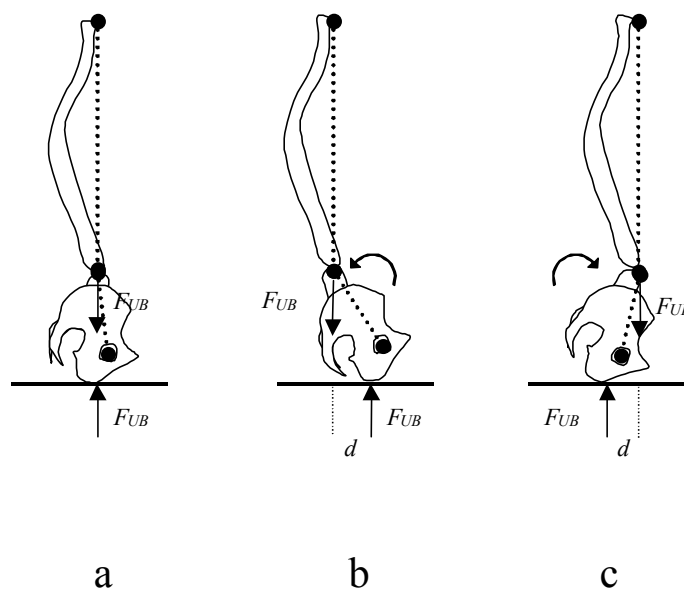


Figure 2.2 Link segment model of the pelvis and spine showing how the angle of the pelvis affects the curvature of the lumbar spine and the torques acting on the pelvis. a). The joint reaction force acting on the pelvis due to its link with the trunk (F_{UB}) is vertically aligned with the seat reaction force ($-F_{UB}$). Since (F_{UB} and $-F_{UB}$) are co-linear there is no net torque. b). Posterior rotation of the pelvis relative to the trunk produces flexion of the lumbar spine. The forces (F_{UB} and $-F_{UB}$) in the resulting position give rise to a force couple acting on the pelvis in the direction of further posterior rotation. c) Anterior rotation of the pelvis produces extension of the lumbar spine. The forces (F_{UB} and $-F_{UB}$) in this position produce an anterior moment acting on the pelvis.

An analysis of the effects of the forces acting on the pelvis can be performed using principles of force systems (Meriam & Kraige, 1993). For the pelvis to remain stationary in sitting, the sum of the forces and torques acting on the pelvis must equal zero. If two equal and opposite co-linear forces are applied to the pelvis, there is no net force, and thus no movement (translation or rotation) occurs (Fig. 2.2a). If two equal and opposite, but non co-linear forces act on the pelvis, the resulting force couple produces a free moment (Fig. 2.2b and c). The magnitude of the moment (M) is given by the product of the force (F_{UB}) and the perpendicular distance between the two forces (ie. $M = F_{UB} \times d$). It follows from the equation that the moment (M) acting on the pelvis can be increased by increasing the force (F_{UB}), the perpendicular distance between the line of action of the two forces (d), or both. If two non co-linear, opposing forces are not equal in magnitude or not parallel, the forces on the object will produce a translation in addition to the rotation unless balanced by other forces. Various combinations of sitting position and of chair design produce approximations of force couples acting on the pelvis. For the purpose of this paper, the moments due to these approximations of force couples acting on the pelvis in the direction of anterior pelvic rotation will be referred to as anterior moments. Likewise, the moments acting on the pelvis tending to rotate the pelvis posteriorly will be referred to as a posterior moments. The discussions that follow will only consider the moments acting on the pelvis in the sagittal plane. Although passive force couples affecting pelvic rotation will be described individually, no single force or moment occurs in isolation. For every posture in every chair, there are forces creating posterior and anterior moments acting on the pelvis. In order for a stationary position to exist, the net moment must be zero. If the net moment is not zero, the pelvis will rotate until a new equilibrium is reached. Alternatively other forces such as active muscle forces must re-establish the equilibrium.

A model, which can be used to assess chair design features, consists of the following assumptions:

1. The seated body in the sagittal plane can be accurately represented by four links (shank and foot, thigh, pelvis, and trunk) connected by three joints (knee, hip, and lumbar spine).

2. Rotation of the pelvis in relation to the trunk is indicative of lumbar spine curvature.
3. Paired forces approximating force couples produce anterior or posterior moments acting on the pelvis.
4. The effect of the mass of the pelvis is ignored as its effect is minimal compared with the moments created from other forces acting on the pelvis
5. Passive forces only will be considered.
6. A net moment acting on the pelvis results in either a rotation of the pelvis or in the need for muscular activity to maintain a stable position. A smaller net moment acting on the pelvis from passive forces requires less sustained muscular contractions to maintain a posture and is considered to indicate a more effective chair design. Likewise a larger net moment is considered to indicate a less effective chair design.
7. The framework is further simplified by ignoring forces whose point of action is far removed from the pelvis (ie. arms resting on armrests or a desk, head resting on the hands, etc.)

This framework will be applied to individual design features of chairs to demonstrate the forces they create affecting pelvic rotation. The net effect of the design features of a particular chair for a particular purpose can then be assessed.

Passive forces acting on the pelvis due to hip angle

The effect of particular muscles and ligaments is altered in different degrees of flexion or extension of the hip joint. For example the hip adductors act as flexors when the hip is in extension and as extensors when the hip is in flexion (Kapanji, 1970). Therefore the term extensor (or flexor) tissues will be used to include all muscle and connective tissue which, when put under tension in a particular position of the hip, will act on the hip to produce an extension (or flexion) torque. Passive tension in the extensor tissues (F_{EXT}) combined with a joint reaction force through the hip ($-F_{EXT}$) form a force couple to produce a posterior moment tending to rotate the pelvis posteriorly (Fig. 2.3a). Likewise passive tension in the hip flexor tissues (F_{FL}) combined with a hip joint reaction force ($-F_{FL}$) produce an anterior moment (Fig. 2.3b). A neutral position of the hip exists where the posterior moment due to the extensor tissues balances the anterior moment due to flexor tissues (Fig. 2.3c).

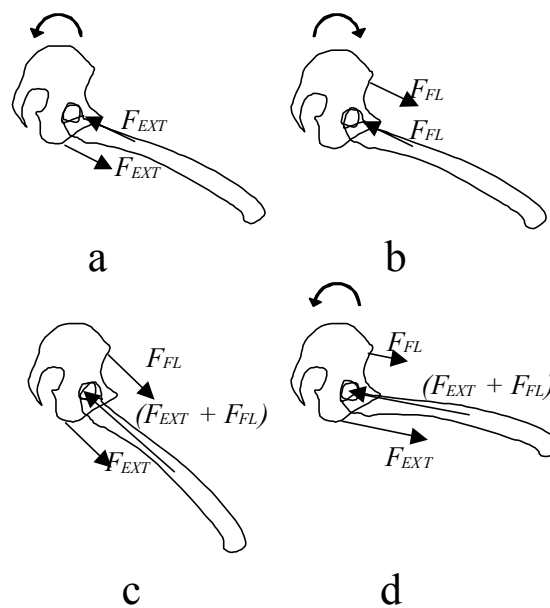


Figure 2.3 Effect of hip flexion on moments acting on the pelvis. a). Passive tension in the extensor structures (F_{EXT}) combined with a joint reaction acting on the pelvis through the hip joint ($-F_{EXT}$) produce a posterior rotational moment acting on the pelvis. b). Passive tension in the flexor structures (F_{FL}) likewise when combined with a joint reaction acting on the pelvis through the hip joint ($-F_{FL}$) produce an anterior rotational moment acting on the pelvis. c). A position of equilibrium exists when the anterior and posterior moments are equal and no net rotational moment is produced. d). Flexion of the hip such that F_{EXT} is greater than F_{FL} creates a net posterior moment acting on the pelvis.

Mandal (1981) considered an angle between the long axis of the trunk and the thigh (trunk–thigh angle) of less than 135 degrees to be the main cause of the concurrent flexion of the lumbar spine which occurs in sitting. Although the angle of 135 degrees is a reasonable approximation, the trunk-thigh angle below which concurrent posterior rotation of the pelvis and thus flexion of the lumbar spine occurs is not only dependent on the flexibility of the hips (Bridger et al., 1989b) and the knee joint angle (Yasukouchi & Isayama, 1995), but varies from one person to the next (Norkin & Levangie, 1992). With hip flexion beyond the onset of concurrent rotation of the pelvis, increased passive tension in the extensor tissues combined with decreased passive tension in the flexor tissues creates a net posterior moment (Fig. 2.3d).

Stand-sit postures associated with a trunk-thigh angle of 135 degrees or greater can reduce or even eliminate this posterior moment (Bridger et al., 1989a; Yasukouchi & Isayama, 1995). Abduction of the flexed hips can also reduce the posterior moment. Maximal abduction of the hip, however as occurs in lateral splits or “lotus position” would tend to rotate the femur externally on the pelvis or, conversely, if the femur is unable to rotate further would result in a moment tending to rotate the pelvis anteriorly. (Kapanji, 1970).

Passive forces acting on the pelvis due to knee angle

Passive tension in the hamstrings and a joint reaction force through the hip joint form a force couple producing a posterior moment. Similarly, passive tension in rectus femoris combined with a joint reaction force through the hip produce an anterior moment. For a given knee angle, there is a hip angle where the anterior and posterior moments are balanced and no net moment is produced from the two joint muscles (Yasukouchi & Isayama, 1995) (Fig. 2.4a).

Extending the knees beyond this position of equilibrium creates a net posterior moment (Norkin & Levangie, 1992) (Fig. 2.4b) which can be counteracted passively by an increased trunk-thigh angle. For example, low automotive seats associated with greater knee extension than higher seats are designed with a more reclined backrest resulting in a larger trunk-thigh angle (Judic et al., 1993). The net moment on the pelvis in the two positions (a higher, more upright seat with knees more flexed and a lower, more reclined seat with the knees more extended) is therefore largely unchanged. Flexion of the knees beyond the position of balance increases the passive tension in the rectus femoris while decreasing the tension in the hamstrings creating a net anterior moment (Fig. 2.4c). A kneerest in a kneelsit chair, tucking one's feet under the chair, or sitting on one's feet thus create anterior moments.

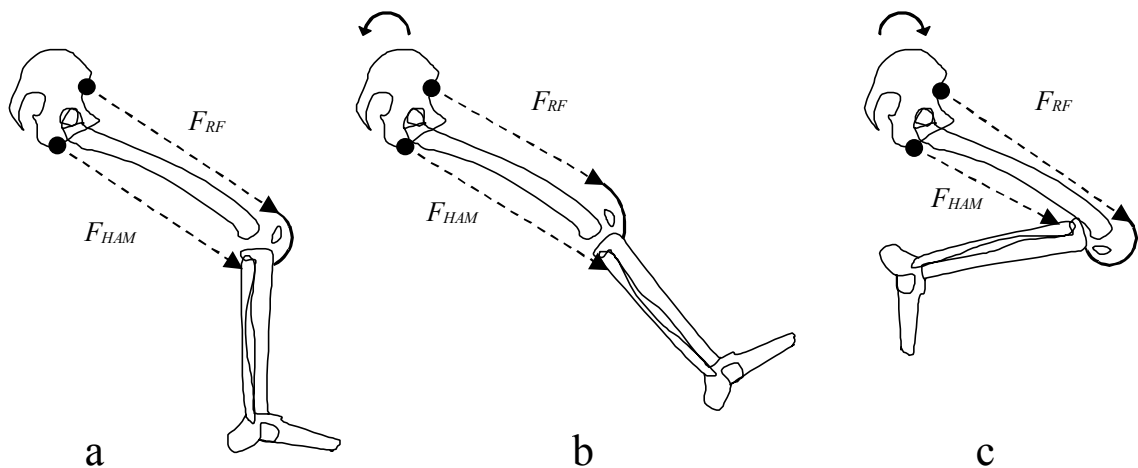


Figure 2.4 Effect of knee angle on moments acting on the pelvis. a). the anterior moment created by the passive stretch on rectus femoris F_{RF} equals the posterior moment from the hamstrings F_{HAM} , and no net rotational moment is produced. b). When the knee is extended further, (F_{HAM}) is greater than (F_{RF}) and a net posterior moment is produced. c). When the knee is flexed, a net anterior moment is produced.

Passive forces acting on the pelvic link due to its angle with the trunk

The position of the lumbar spine can produce moments acting on the pelvis in the same way as the position of the hips. That is, tension in the soft tissues from increased flexion of the lumbar spine as shown in Figure 2.2b will produce a moment tending to extend the lumbar spine or, in other words rotate the pelvis anteriorly (the moment produced is thus in the opposite direction to the arrow in Figure 2.2b which indicates the direction of movement). Likewise tension in the soft tissues from increased extension of the lumbar spine will produce a posterior moment acting on the pelvis.

Gravitational forces acting on the pelvis

In a balanced, upright sitting position on a horizontal seat, the weight of the trunk (the gravitational force acting on the mass of the trunk) transmitted to the pelvis is centred over the ischial tuberosities with about 25% of the body weight (slightly less than the weight of the legs and feet) transmitted to the floor through the feet (Norkin & Levangie, 1992). The weight being supported by the ischial tuberosities and the opposing support from the seat are co-linear and no force couple and thus no moment acting on the pelvis is produced (Fig. 2.2a). When the force due to the weight above the pelvis and the seat reaction force are not vertically aligned, a moment acting on the pelvis is produced.

When the pelvis rotates posteriorly, the weight transmitted through the link between the pelvis and the trunk moves posteriorly relative to the base of support creating a posterior moment (Fig. 2.2b). The further the centre of gravity is behind the base of support, the greater the moment produced. If there are no other forces to counteract this posterior moment such as a back support or active muscle contraction, the pelvis continues to rotate until the sacrum contacts the seat creating a new position of stability.

Likewise an anterior moment is produced when the pelvis is rotated forward. In the absence of active muscle contraction, the pelvis will continue to rotate anteriorly until a new stable position is reached where the posterior moments equal the anterior moments. Increased posterior moments can result from the decreasing hip angle or contact between the seat and the pubic symphysis or perineum which can move the base of support anteriorly.

When the centre of the base of support is anterior to the centre of gravity of the trunk, a posterior moment is created. An anterior base of support can occur with a seat with a central ridge (Morrow, 1984), a bicycle seat or a horse saddle. Alternatively the same effect occurs when the femur exerts an upward force through the hip joint. This can occur with sitting near the front of a reclined seat (Fig. 2.5a) or with other seat characteristics producing pressure under the proximal thighs greater than that necessary to support the weight of the thighs themselves.

When the base of support is posterior to the centre of gravity of the trunk as can occur with an inclined seat or the upward slope at the back of a horse saddle, an anterior moment is produced. There are, however two arguments against the use of an upward slope at the back of a seat. Firstly the posterior buttocks and pelvis contacting a forward sloping posterior support will result in a horizontal force tending to slide the person forward on the seat. Secondly if the prominence is in the central portion of the rear of the seat undesirable pressure on the lower sacrum and coccyx may be produced.

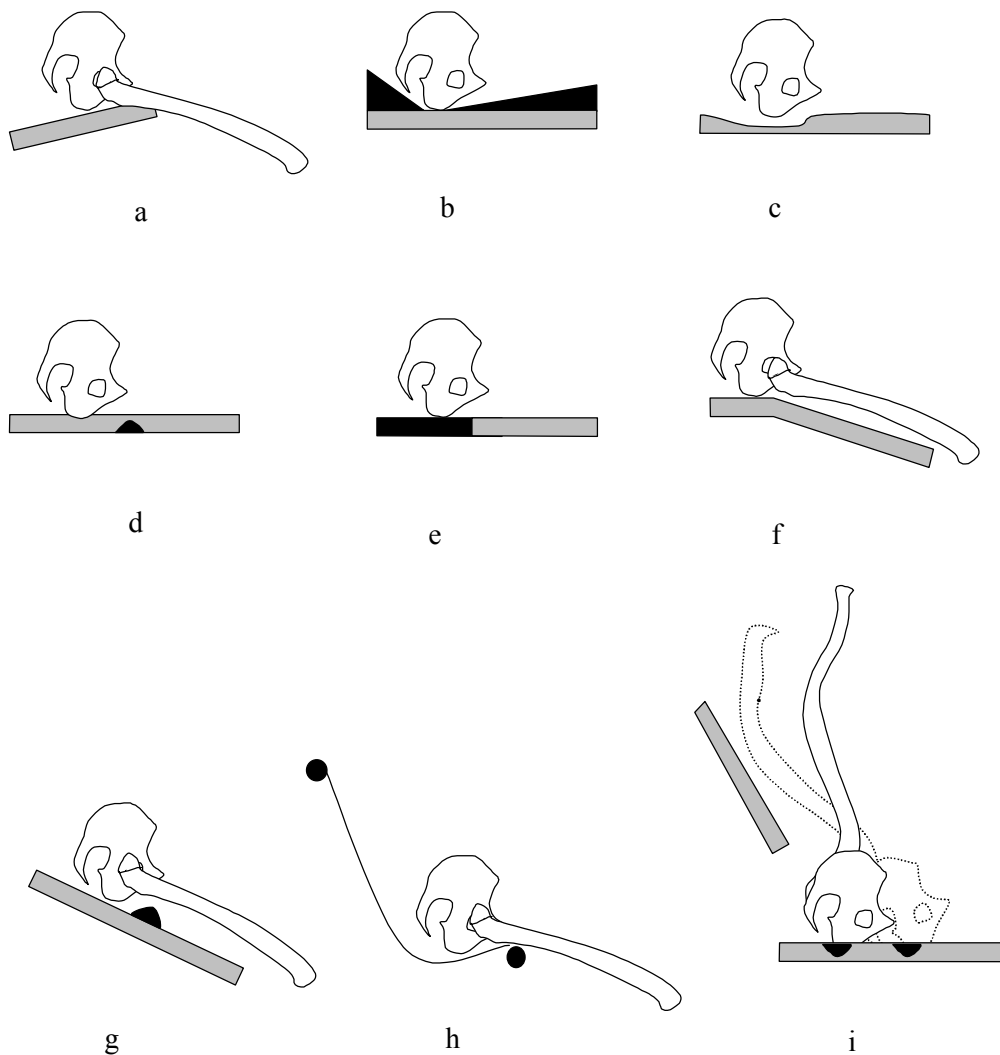


Figure 2.5 Seat designs: a). When sitting at the front of a reclined seat the ischial tuberosities are prevented from sliding forward by the front edge of the seat. This situation can also result in an upward force on the pelvis through the hip joint resulting in a posterior moment acting on the pelvis. b). Wedges in front of and behind the ischial tuberosities (Chee, 1992). A similar effect is produced by woven seats in some traditional Shaker chairs from the 18th century (Andrews & Andrews, 1964). c). A ‘Step face or anti-thrust barrier to the user’s ischial tuberosities’ for wheelchair cushions (Jay, 1994). d). A transverse ridge under automotive seats (Sperr, 1985). e). Softer foam on the posterior portion of the seat (Gregory, 1987). f). A horizontal support under the pelvis with the seat front inclined (Yu & Keyserling, 1989; Graf et al., 1993). g). A small cushion in front of pelvis (Mandal, 1984). h). A slung seat with a bar in front of the ischial tuberosities as on traditional Maldivian chair (Blair, 1991). i). Two soft foam inserts for location of the ischial tuberosities in upright and slumped postures (Owen, 1993).

Forces acting on the pelvis parallel to the chair surfaces

The force of gravity acting on the mass of the trunk acts in a vertical direction. Sitting on a flat horizontal seat therefore does not produce any forces acting parallel to the seat surface (Fig. 2.2). Sitting on either an inclined or reclined seat will, however produce a component of the gravitational force parallel to the seat surface tending to slide the occupant on the seat. In the absence of other forces, an inclined seat will slide the occupant forward, while a reclined seat will slide the occupant back on the seat.

Forces parallel to the seat in a forward direction also result from the backrest acting on the trunk or pelvis. If the occupant is to be prevented from sliding forward, an equal force must be applied in the opposite direction. The main sources of these posteriorly directed forces acting on the pelvis are either the fixed femur acting via the hip joint (as when the feet are on the ground or when a kneerest prevents forward movement) or seat reaction forces acting on the pelvis from the seat. Seat reaction forces can be in the form of friction between the seat surface and the back of the thighs and pelvis. In the absence of forces other than friction, however, constant movement and postural adjustments that occur with sitting result in the body gradually sliding forward on the seat. (Cranz, 1998).

A selection of the many seat designs which have been proposed to resist forward movement of the pelvis on the seat are shown in Figure 2.5b-i. Other designs use force against the perineum to resist the forward movement as occurs with bicycle seats and horse saddles. Mandal (1981) suggested that the posture in horseriding was the ideal sitting posture. Saddle-shaped seats for office use have been described by Gale et al. (1989) and Bendix (1994). Other seat shapes with a central ridge to reduce forward movement of the pelvis have been patented by Arnold (1990) and Powell (1991). Festervoll (1994) presents a discussion of still other variations in seats including flexible contours that alter during use.

The interactions of the forces acting on the body when a backrest is combined with the seat are

more complex than when considering a seat on its own. Goossens and Snijders (1995) analysed and measured forces parallel to the seat and backrest surfaces for seats reclined by up to 20 degrees. For a passive seated occupant, any angle between the seat and the backrest greater than 95 degrees produced forces which tended to slide the occupant forward on the seat (Fig. 2.6a). In the absence of factors that resist the forward movement of the pelvis, the trunk would slide down the backrest, the pelvis slide forward on the seat, and the pelvis rotate posteriorly increasing lumbar flexion.

In reclined postures with the seat reclined by more than 20 degrees and the backrest reclined by greater than 40 degrees, the tendency to slide down the seat was reversed. That is, the thighs and pelvis would tend to slide towards the back of the seat (Fig. 2.6b). Reclining lounge chairs are examples of this reclined position and thus, with an appropriately contoured backrest, are capable of producing an anterior moment acting on the pelvis.

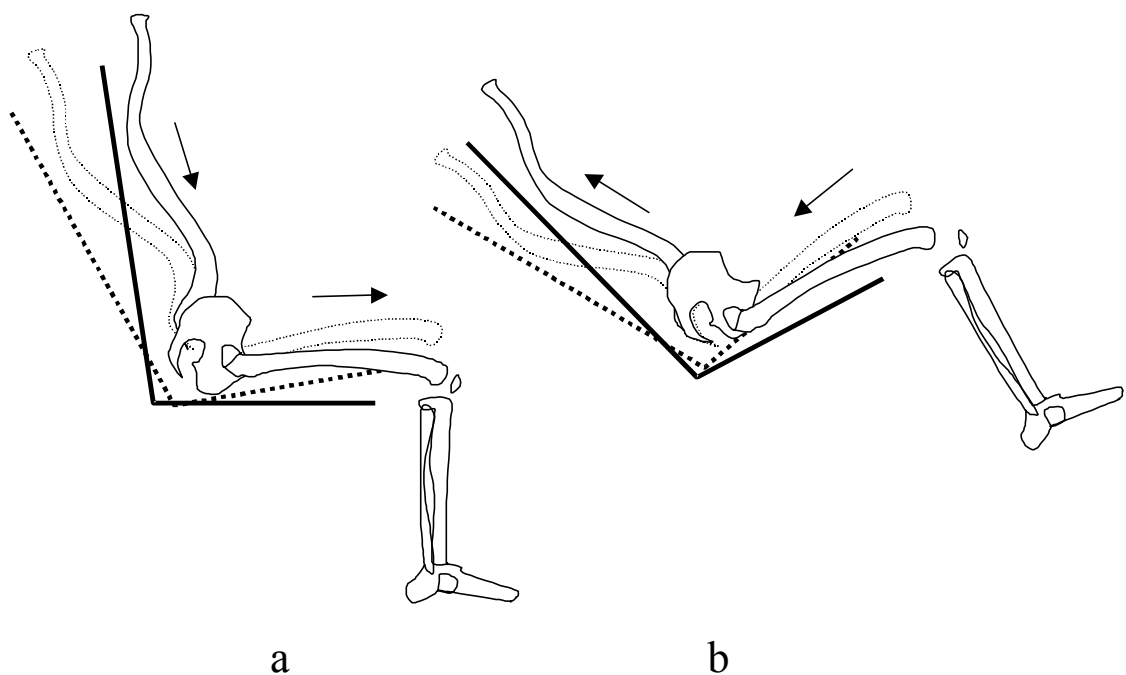


Figure 2.6 Forces parallel to chair seat and backrest. For thigh angles greater than 95 degrees, forces are created tending to slide the occupant in relation to the seat and backrest. a). If the seat is reclined less than 20 degrees the occupant will tend to slide forward. b). If the seat is reclined by more than 20 degrees and the backrest by more than 40 degrees, the occupant will tend to slide towards the back of the seat (Goossens & Snijders, 1995).

Effects of a backrest

The most common design feature in chairs for maintaining spinal curvatures is a backrest with a lumbar support (Pheasant, 1992). It is recommended that the lumbar support be of a smaller diameter than the standing lumbar lordosis and be placed near the level of the third lumbar vertebra (McKenzie, 1981; Yu & Keyserling, 1989). Zacharkow (1998) suggested that the lower support on the backrest should be at the upper sacrum or ilium rather than directly on the lumbar spine. The forces specific to sitting that tend to reduce the lumbar lordosis do not act directly on the lumbar spine, but rather produce a posterior moment acting on the pelvis which in turn affects the lumbar spine. Zacharkow (1998) argues that a backrest is more effective supporting the pelvis directly without the intervening mobile segments of the lumbosacral spine.

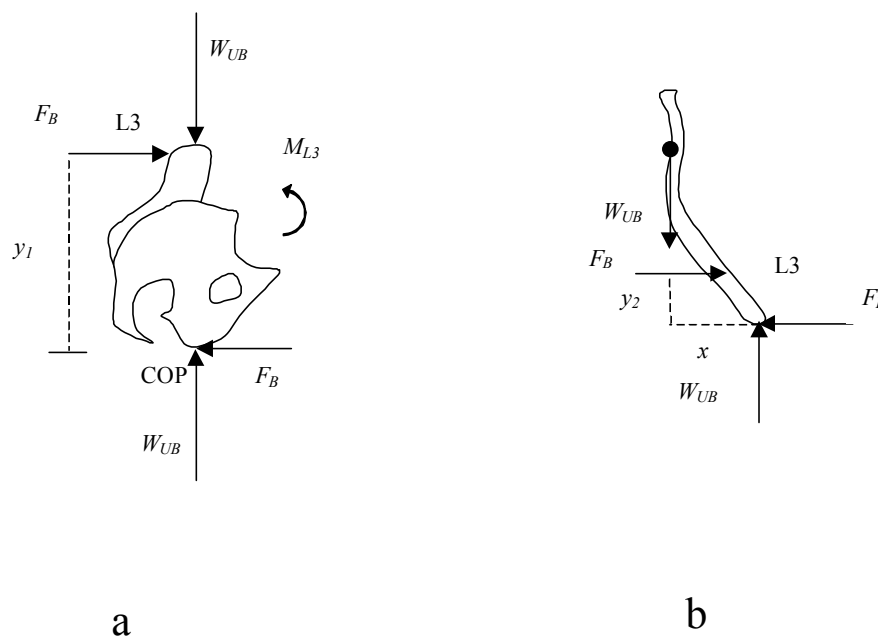


Figure 2.7 Effect of a backrest on moments acting on the pelvis. a). A free body diagram representing the effect of a backrest force (F_B) and a seat reaction force (F_B) acting on the pelvis. A counterclockwise free moment (M_{L3}) is shown acting on the pelvis as would occur in most sitting postures. For a given backrest force F_B , the maximum clockwise moment is created when the point of application is at L3 (y_1 is the largest). (b) Any backrest force above L3 will result in a joint reaction force acting on the pelvis from the trunk in the same direction and of the same magnitude as if the backrest force were being applied at L3. In addition a backrest force acting on the trunk (in combination with the horizontal joint reaction force from the pelvis) will create a clockwise torque acting on the trunk. As the trunk reclines and the centre of gravity of the trunk moves posteriorly in relation to its base of support (x increases), a counterclockwise torque is created. Therefore in order to maintain equilibrium as the trunk reclines, either the backrest force (F_B) must increase or the point of application of the backrest force must rise (y_2 increase).

The effect of a backrest acting directly on the pelvic link is represented in Figure 2.7a. A free moment of magnitude M_{L3} is shown as would be the result of forces acting on the pelvis due to trunk-thigh angle, knee angle or the weight of the trunk acting on the pelvis. The backrest force acting on the pelvis (F_B) is assumed to act in the horizontal plane and the weight of the trunk (W_{UB}) is shown to be located directly above the centre of pressure (COP) on the seat (the effect if W_{UB} is anterior or posterior to COP is discussed under *Gravitational forces acting on the pelvis* and must not be neglected). To meet the conditions for static equilibrium, all forces and torques acting on the system must sum to zero. Linear equilibrium occurs when the backrest force (F_B) is balanced by an equal and opposite horizontal force acting on the pelvis through the seat known as horizontal seat reaction force (F_B). Angular equilibrium results when all torques acting on the pelvis are balanced, that is, when the counterclockwise torque (M_{L3}) is balanced by the clockwise torque ($F_B \times y_1$). If the point of application of the backrest force is lower (y_2 becomes smaller), the backrest force and the corresponding horizontal seat reaction force (F_B) must become larger. The necessary backrest force is thus minimised (assuming the pelvic link is rigid) when the backrest is applied at L3 (y_2 is largest). The lower the point of application of the backrest force on the pelvis (smaller y_2), the larger the backrest and seat reaction forces must be to maintain equilibrium.

If the backrest force F_B is applied above L3 on the trunk, a horizontal joint reaction force in the same direction and of the same magnitude from the trunk will act on the pelvis at L3 as if the backrest were acting directly at L3. In addition a backrest force on the trunk itself results in a torque towards lumbar flexion as shown in Figure 2.7b. At equilibrium, the clockwise torque acting on the trunk about L3 ($F_B \times y_2$) is balanced by the counterclockwise torque ($W_{UB} \times x$). If the backrest force is applied higher on the trunk (larger y_2), the clockwise torque is increased.

As the trunk reclines (x increases), the counterclockwise torque ($W_{UB} \times x$) increases. Thus in order to maintain equilibrium as the trunk reclines the clockwise torque ($F_B \times y_2$) must increase

by either the magnitude of the backrest force (F_B) increasing or the point of application moving further from L3 (y_2 increases). (As the sitter reclines, the assumptions that the backrest force is horizontal and that W_{UB} acting on the pelvis is directly over COP are no longer valid. The effects of a change in point of application or magnitude of backrest force are, however qualitatively as discussed above.)

The minimum backrest force is required to counteract a posterior moment acting on the pelvis when it is applied at L3. The lower on the pelvis the point of application of the backrest force, the greater the backrest force required to produce the same torque. The backrest force being applied higher on the trunk does not further affect the horizontal joint reaction force acting on the pelvis, but rather increases the torque towards lumbar flexion on the trunk itself.

The backrest force may be applied at more than one point as occurs with a high backrest or separate pelvic and thoracic supports. The net effect of multiple backrest forces would simply be the sum of the effects from the individual forces.

Application to chair selection

Table 2.1 provides a summary of the main chair design features described earlier in this chapter and how they affect moments acting on the pelvis. There are interactions between some factors such as hip and knee angles. Other factors can have opposing effects. For example, a more open hip angle reduces the posterior moment due to the hip angle, but can increase the tendency of the occupant to slide forward increasing the posterior moment.

Table 2.1 Summary of effects of various chair design features. The conditions under which each feature will result in an anterior or posterior moment acting on the pelvis.

| Design feature | Posterior rotation of pelvis (decreased lordosis) | Anterior rotation of pelvis (increased lordosis) |
|--------------------------------------|---|---|
| Trunk-thigh angle | Trunk-thigh angle less than 135 degrees (variable with individual's joint mobility and knee position) | Trunk-thigh angle greater than 135 degrees (variable with individual's joint mobility and knee position) |
| Knee angle | Knee extension (variable with hip position and muscle length) | Knee flexion (variable with hip position and muscle length) |
| Centre of gravity /base of support | Centre of gravity of trunk posterior to Ischial Tuberosities | Centre of gravity of trunk anterior to Ischial Tuberosities |
| Inclined Seat | When forward movement is not prevented the occupant slides forward resulting in posterior moments from other forces | When forward movement is resisted by other forces an anterior moment is created |
| Reclined Seat | Ineffective backrest or excessive seat depth | Effective backrest |
| Forces parallel to seat and backrest | Seats reclined less than 20 degrees: Seat-Backrest angle greater than 95 degrees | Seats reclined greater than 20 degrees: Backrest reclined greater than 40 degrees |
| Backrest | Backrest high on trunk | Most effective near level of centre of lumbar rotation (L3). Effectiveness reduces with distance from L3 |
| Seat characteristics | Forces insufficient to prevent occupant sliding forward on seat | Forces sufficient to prevent forward movement on seat. |

An illustration of the application of these principles to assessment of three school chairs (Fig. 2.8) is shown in Table 2.2. The postures used by school students are divided between sitting forward as when writing or drawing and sitting back as when listening. Aagaard-Hansen and Storr-Paulsen (1995) assessed the three types of school chairs shown in Figure 2.8 in classroom settings. Chair 2.8a was a fairly traditional chair with a slightly reclined seat. Chair 2.8b differed only in that the seat had a three degree incline. The chair shown in Figure 2.8c which was constructed according to principals advocated by Mandal (1984) had a significantly higher seat shaped to be level under the pelvis and inclined forward under the thighs. Due to the height of the seat of chair 2.8c a footrest was included in the school desk for use when sitting back.

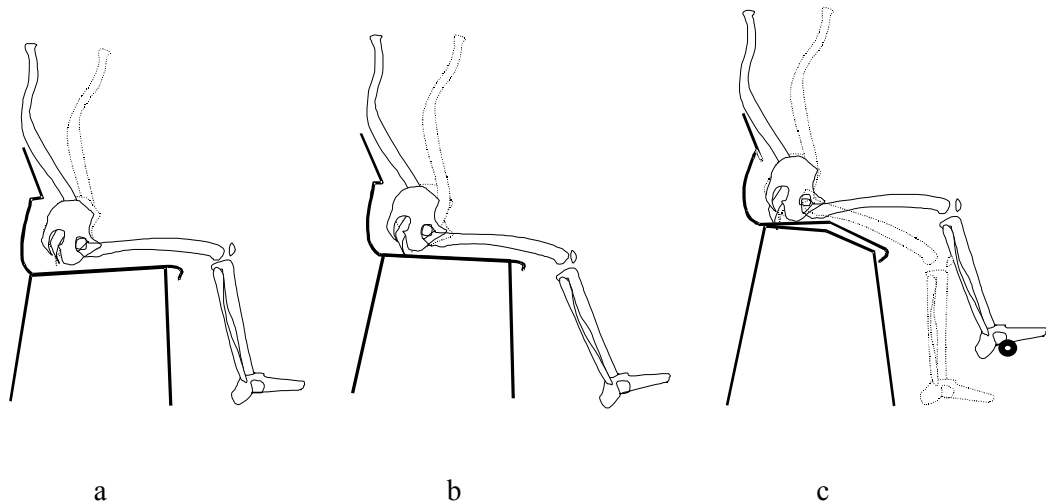


Figure 2.8 Three school chair designs assessed by Aagaard-Hansen and Storr-Paulsen (1995). a). Standard chair with slightly reclined seat. b). Intermediate chair identical to chair a, but with seat inclined by three degrees. c). Chair advocated by Mandal (1994) with higher seat the front of which is inclined and including a footrest for use when sitting back.

In the forward posture, the major differences between the chairs are in the effects from the trunk-thigh and knee angles and the seat angle. As the seat angle changed from reclined in chair 2.8a to a marked incline in chair 2.8c, the posterior moment acting on the pelvis due to trunk-thigh angle decreased and the anterior moment from the seat angle increased. The greater knee extension in chair 2.8b results in a slightly greater tendency towards a posterior moment when

compared with chair 2.8a. The knee position in chair 2.8c is fairly neutral and thus exerts minimal force on the pelvis. The net passive posterior moment and thus the moment created by muscular effort necessary to maintain a forward posture is greatest in chair 2.8a. The least muscular effort is required to maintain a forward posture in chair 2.8c, with chair 2.8b between the two, but closer to chair 2.8a.

Table 2.2 Effects of three school chair designs on forces acting on the pelvis. The moment acting on the pelvis from each feature is shown as being in an anterior direction (A), posterior direction (P) or having minimal effect (-). Up to three letters are used to indicate comparisons within a particular feature. In this example the effects are added although the letters do not necessarily indicate absolute magnitudes or relative magnitudes of forces between features. For sitting forward, chair c produced a small net anterior moment and chair a produced the largest net posterior moment. When sitting back, chair a produced a smaller moment than chair b or c.

| Posture | Sitting forward | | | Sitting back | | |
|--------------------------------------|------------------|--------------------|---------------|------------------------|--------------------|--------------------|
| | Chair | a | b | c | a | b |
| Trunk-thigh angle | PPP | PP | - | P | - | PP |
| Knee angle | P | PP | - | - | P | - |
| Centre of gravity /base of support | - | - | - | P | P | P |
| Seat angle | P | A | - | A | P | - |
| Forces parallel to seat and backrest | - | - | - | - | P | P |
| Backrest | - | - | - | AA | A | A |
| Seat characteristics | - | - | A | - | - | - |
| Summary | Marked Posterior | Moderate Posterior | Mild Anterior | Possibly Mild Anterior | Moderate Posterior | Moderate Posterior |

The three chairs perform quite differently for sitting back than for sitting forward. Although people frequently do not use chairs as the designers intend (Dainoff, 1994), for the analysis presented it is assumed that when reclining, the students in chair 2.8c use the footrest provided and the students in all three chairs sit at the back of the seat with the backrest contacting the lumbar spine. The thigh-trunk angle was smallest in chair 2.8c creating the greatest posterior

moment followed by chair 2.8a. The trunk-thigh angle in chair 2.8b resulted in a minimal effect. Although the effects of the knee angles when sitting back are similar to when sitting forward, the magnitude of the effect is reduced. The reclined seat in chair 2.8a resulted in the backrest being slightly more effective and the least tendency to slide forward on the seat. Chair 2.8c and 2.8b proved less desirable for sitting back than chair 2.8a. In the comparisons by Aagaard-Hansen and Storr-Paulsen (1995) students preferred chair 2.8c followed by chair 2.8b then chair 2.8a suggesting that sitting forward may have been a greater factor in the student's preferences than sitting back.

Conclusions

Optimal performance of sitting tasks require combinations of various postures. One of the major challenges to seating design and selection is how to maintain “normal” spinal curvatures throughout the range of postures necessary for performing the required tasks without the harmful effects from sustained muscle contraction. Sitting tends to produce forces that create a net moment acting on the pelvis. The result is either an alteration in spinal posture or muscle contractions to maintain spinal curvatures. The challenge therefore is how to minimise the passive moments acting on the pelvis.

This paper presents a qualitative method of analysing chair designs by their mechanical effects on the pelvis and thereby on spinal postures or static muscle contractions. A system quantifying the effects of design features could be developed and tested in future studies. Many other areas relating to seating are vitally important when assessing seating, but outside the scope of this paper. A partial list includes: seat and backrest comfort, mobility and adjustability of the seat and backrest, functional design of the backrest, the workstation and task design, cost benefit analysis, workplace practices, aesthetics and status. All of these factors as well as a thorough mechanical analysis are ideally taken into consideration when evaluating seating.

3

Preferred seat height of Year 11 high school students

Previous studies investigating seat height for school chairs have used a fixed seat angle and varied the seat height. Chairs manufactured for school populations however have dimensions including the height of the front of the seat determined by applying ergonomic principles to anthropometric dimensions. The current study investigated the height of the rear of the seat or, in other words, the seat angle for one age group of school students. The purposes of this study were to: (i). Ascertain if there is a difference between student's preferred rear seat height (PRSH) during a simulated classroom activity and a brief adjustment period; (ii). Determine the PRSH for school chairs for Year 11 high school students with a 445 mm front seat height; and (iii). Determine the relationship between stature, popliteal height, desk height and PRSH. Two groups of 16 Year 11 students used experimental chairs with a 445 mm front seat height (fifth percentile shod popliteal height of target population) and adjustable rear seat height in two related experiments. (i). Students found their PRSH during a 30 minute simulated classroom activity using a 735 mm desk. (ii). Using a brief adjustment period, students found their PRSH using desk heights of 720 mm, 735 mm and 800 mm. Eight students also adjusted a desk to their preferred height and the seat to their PRSH. No differences were found in PRSH between the two adjustment periods for the same desk height. Significant negative correlations occurred between both popliteal height and stature and PRSH. Average PRSH ranged from 439 mm to 454 mm depending on desk height. A regression equation was derived expressing PRSH as a linear function of popliteal height and desk height. Seat height preferences can be determined using a relatively short adjustment period.

Introduction

Recommendations for the height and angle of school chairs seats vary considerably. Australian Standards (1995) and Parcels, Stommel and Hubbard (1999) recommended the seat height (measured at the front of the seat) approximate the users popliteal height. Mandal (1984) and (Mandal 1994) recommended seat heights (measured at the rear of the seat) of 10 to 15 cm higher than the popliteal height providing that the seat was inclined (angled forward) by approximately 15 degrees. If the height of the front of the seat corresponding to the recommendations by Mandal (1984 and 1994) is calculated, it also approximates the user's popliteal height. The recommendations by Mandal (1984 and 1994), Parcels, Stommel and Hubbard (1999) and Australian standards (1995) thus agree that the height of the front of the seat should approximate the popliteal height of the user. The real disagreement is between a seat with a 15 degree incline proposed by Mandal (1984 and 1994) and a seat reclined by up to five degrees as advocated by Australian Standards (1995) or, in other words the disagreement is related to the recommended height of the rear of the seat.

In the school setting it is not possible to have a different size chair to suit each student. A limited number of chair sizes are used to accommodate the range of ages and sizes of school students from preschool through high school (6 sizes in Australia (Australian Standards, 1995), 11 in Korea (Cho, 1994), 9 in Japan (Hibaru & Watanabe, 1994). Although adjustable chairs would be ideal, they are not possible in most school settings due to cost and other practical considerations. Therefore one size of chair is required to accommodate a range of students of different shapes and sizes. If the height of the front of the seat would be set at the average popliteal height of the target population, the unacceptable situation would result where half of the students would be unable to sit with their feet flat on the floor. A more acceptable determination of the seat height would be to ensure that 95% of the population using a particular size chair are to be able to sit with their feet on the floor. The height of the front of the seat would therefore equal the fifth percentile shod popliteal height of the users of each size chair (Pheasant, 1992). The factor remaining to be determined regarding seat position is the appropriate height of the rear of the seat not just for one individual, but for the whole population

using each size chair.

Kroemer (1994) reviewed methods and measurements used to assess seating and concluded that preference of the user and performance of the required tasks were the most valid criteria for evaluating chair design features. A continuous variable such as seat height would be difficult, if not impossible to assess by using variations in student's performance. Student preferences on the other hand have previously been found to be a reliable means of assessing school seating (Aagaard-Hansen & Storr-Paulsen, 1995) and provide a viable means of assessing a continuous variable such as rear seat height.

Mandal (1984) used student's preferences in an attempt to determine the correct height for school furniture. His subjects performed a brief writing task while determining their preferences of seat and desk height. Zacharkow (1988) suggested that a type and duration of usage similar to that normally performed in a chair was necessary for accurate assessment of seating. Students in the classroom do more than just writing for brief periods. Rather they perform a variety of tasks requiring a range of postures including sitting forward and sitting back for class periods of 30 minutes or more (Yeats, 1997) which may affect their preferred seat heights.

Various anthropometric measurements have also been related to preferred seat height. Mandal (1984) described preferred rear seat height as a proportion of the subject's stature, while Noro (1994) stated that the preferred seat heights were normally distributed around the subject's popliteal heights. Hibiru and Watanabe (1994) and Noro (1994) further suggested that the distance between seat height and desk height was a function of the user's sitting height. The finding by Graf, Guggenbuhl, and Krueger (1993) that preferred seat height was affected by seat angle was in agreement with the 10-15 cm difference in the preferred rear seat heights found by Mandal (1984) using a 15 degree inclined seat and Noro (1994) using a horizontal seat.

Factors that may influence the choice of preferred seat height of school chairs thus include the duration and nature of tasks to be performed, the seat and desk heights and angles, and the anthropometric characteristics of the population. The purposes of the current study were to clarify appropriate seat position for one size school chair by: (i). Ascertaining if there is a difference between the preferred rear seat height (PRSH) for subjects using a 30 minute adjustment period performing a simulated classroom activity and those using a brief adjustment period; (ii). Determining preferred rear seat height for school chairs for Year 11 high school students performing a simulated classroom activity with the height of the front of the seat at 445 mm; and (iii). Determining the relationship between stature, popliteal height, desk height and preferred rear seat height.

Methods

Subjects and anthropometric measurements

Following approval of the study by the Griffith University Human Research Ethics Committee, students in Year 11 at a local private high school were recruited to participate in the study. Students in the second semester of Year 11 were chosen for the current study as they approximate the midpoint in age of the students in Years 11 and 12 who use the largest size chair in Australian schools. The students were not selected for gender or anthropometric characteristics and were dressed in their usual school uniforms including shoes. Informed consent was obtained from the students, their parent or guardian and a representative of the school prior to participation in the study. Stature and popliteal height were measured with shoes on to reflect the functional dimensions of the students in the classroom. Stature was measured to the nearest 5 mm using a stadiometer. Popliteal height was measured with the students sitting on a table with the front edge of the table touching the back of the knees. A horizontal surface under the feet was raised until both the heels and soles of the shoes rested on the surface. The vertical distance between this horizontal surface and the table was measured with a tape measure to the nearest 5 mm. This weight bearing method of measuring popliteal height was used as it was considered to represent a more functional measure of the shod popliteal height. Body mass was measured to the nearest kilogram using a spring scale (Seca).

Experimental chair and desk

Two identical experimental chairs (Figure 3.1) were constructed which consisted of: (i). A commercial five-star office chair base on glides rather than the usual castors, a screw pedestal height adjustment to enable the height to be set accurately and a seat mechanism with an adjustable seat angle which maintained a constant height at the front of the seat (Taskmaster, Richard Small Pty. Ltd. Melbourne, Victoria); and (ii). An injection moulded plastic seat and backrest from a commercial school chair (Dura Pos size 6, Woods Furniture, Richmond, Victoria). The backrest was mounted in the same position in relation to the seat as on the original chair (175 mm above the back of the seat forming an angle of 95 degrees with the seat).

The seats on the experimental chairs had a slightly textured surface, were flat front to back under the weight-bearing surface with a rounded front edge (20 mm radius) and had a maximum lateral dishing of 15 mm.

The seat including attached backrest was able to be adjusted and locked at any seat angle from - 5 degrees to + 10 degrees (A horizontal seat is deemed to be zero degrees with an inclined seat expressed as a positive seat angle and a reclined seat as a negative seat angle). The height of the front of the seat was set at 445 mm -the fifth percentile popliteal height for Australian students in Years 11 and 12 (Sebel Furniture, 1995). Students were instructed how to adjust the rear seat height of the chair and were required to demonstrate their ability to properly adjust the seat prior to commencement of the experiment.

Flat horizontal desk surfaces as used in the students' classrooms were used in the current study.



Figure 3.1. Experimental chairs showing range of seat angle adjustment.

Assessment of preferred rear seat height using a single fixed desk height

Sixteen students each sat on an experimental chair at a desk as used in their usual classroom (735 mm high) and were instructed to adjust the chair during the task until they were satisfied that they had found the one position they preferred for performing the task, that is, their PRSH.

Two students at a time performed a standard 30 minute task consisting of watching and taking notes on three video segments of between six and eight minutes each followed by two to three minutes of writing answers to written questions. The task was designed to simulate a classroom situation with an appropriate mix of sitting forward writing and sitting back watching and listening. At the completion of the task, each student would be asked if they were satisfied that they had found the seat position that they preferred. The data from any student who was not satisfied with their adjustment of the chair or who had adjusted the chair during the final five minutes of the task would be excluded. PRSH was measured at the midline of the rear weight-bearing surface (300 mm from the front of the seat, approximately under the ischial tuberosities) at the end of the 30-minute task.

Assessment of preferred seat height using three fixed desk heights and one adjustable desk height

A second experiment was conducted to: (i). Test the assumption that a short assessment period as used by Mandal (1984) would give different results than an assessment period comparable to a usual classroom period and (ii). Explore the relationship between desk height, anthropometric measurements and PRSH using three fixed desk heights and one adjustable desk height.

A second group of 16 students using an adjustable height desk performed two trials at each of three desk heights: 720 mm (Sebel Furniture, 1995), 735 mm (the desk height normally used by the students), or 800 mm (Mandal, 1984) which were presented in random order. The students were instructed to take as much time as necessary to adjust the chair to their PRSH for each desk height for work involving a combination of sitting forward as when writing and sitting

back as when listening. When the student was satisfied with the adjustment, they stood up while the seat was measured and the desk was set to the next height.

The final eight students were also instructed and demonstrated their ability to move a variable height desk through its full range of adjustment (710 mm – 820 mm) and performed two additional trials (one immediately prior to and one immediately after the six trials with fixed desk heights) for which they were instructed to adjust both the desk and seat heights to their preferred positions.

Statistical analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS, Ver7.5.1). All descriptive statistics are reported as means \pm one standard deviation. The mean PRSH and preferred desk height for the two trials for each subject using each desk condition were used for subsequent analysis. Independent sample t-tests were used to compare the stature, popliteal height, mass and PRSH of the subject groups using a 735 mm desk height for a 30 minute adjustment period and a brief adjustment period. Pearson correlation coefficients were calculated for the data from the brief adjustment period for the relationships between the PRSH and the students' stature, popliteal height and mass. A test was also conducted to determine if the regression lines describing the relationship between popliteal height and PRSH and stature and PRSH were significantly different for each desk height (Neter, Wasserman, and Kutner, 1989). A linear regression equation was derived for the relationship between PRSH, desk height and the independent variable that demonstrated the highest correlations with PRSH. Significance levels for all tests were set to $p= 0.05$.

Results

Assessment of preferred seat height using a single fixed desk height

The subject group consisted of five males and eleven females, had a stature of 1722 ± 81 mm, popliteal height of 517 ± 38 mm and mass of 61 ± 13 kg. All students stated that they had adjusted the chair to their satisfaction and none adjusted their seat in the final five minutes of the trial. Interestingly only two students readjusted their chairs after the first five minutes of the trial. The preferred rear seat height was 439 ± 14 mm (-1.1 ± 2.7 degrees).

Assessment of preferred rear seat height using three fixed desk heights and one adjustable desk height

The subject group consisted of six males and ten females, had a mean stature of 1740 ± 91 mm, mean popliteal height of 510 ± 38 mm and mean mass of 60 ± 9 kg. All students required less than five minutes to adjust their chair (and, for the final eight students their desk) to their preferred positions. There were no statistically significant differences between the two groups of subjects performing the two parts of the experiment with respect to stature, mass, popliteal height, or gender mix, nor was there a statistically significant difference in PRSH for the two groups when each used a 735 mm desk height.

The mean PRSH for the 800 mm desk height was 454 ± 14 mm (1.7 ± 2.7 degrees); for 735 mm desk height 447 ± 15 mm (0.4 ± 2.9 degrees); and for 720 mm desk height 444 ± 16 mm (-0.2 ± 3.1 degrees). The mean PRSH for the three desk heights was 25-26% of mean stature or 87-89% of mean popliteal height.

Pearson correlation coefficients for the relationship between popliteal height and PRSH and stature and PRSH are displayed in Table 3.1. Significant negative correlations were found between popliteal height and PRSH for all desk heights and between stature and PRSH for the 720 mm and 735 mm desk heights. Interestingly, PRSH correlated more strongly with popliteal height than stature at all desk heights. Even though no significant differences were found

between the regression lines for the different desk heights, for descriptive purposes the separate regression lines predicting the effect of popliteal height and stature on PRSH are shown for each desk height in Figure 3.2. Coefficients of Determination (R^2) for regression of popliteal height on PRSH for each desk height (800, 735 and 720 mm) were 0.29, 0.31 and 0.36. For regression of stature on PRSH the R^2 values for each desk height were 0.19, 0.24 and 0.24 respectively.

Table 3.1. Pearson correlation coefficients for the relationship between popliteal height and PRSH, and stature and PRSH at each desk height.

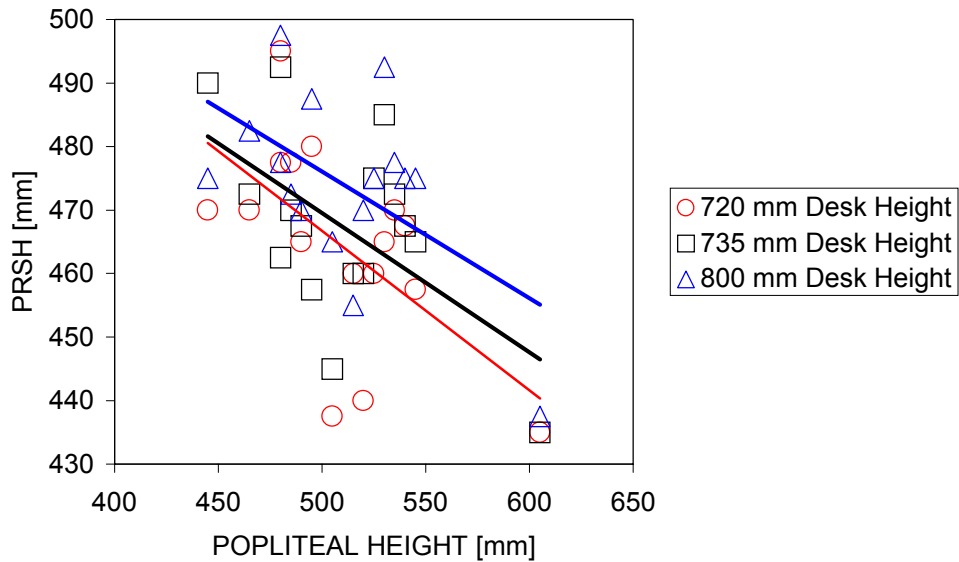
| | Desk height | | |
|--------------------------|--------------------------|--------------------------|--------------------------|
| | 720 mm | 735 mm | 800 mm |
| Popliteal Height vs PRSH | $r = -0.59$ ($p=0.02$) | $r = -0.56$ ($p=0.02$) | $r = -0.54$ ($p=0.03$) |
| Stature vs PRSH | $r = -0.49$ ($p=0.05$) | $r = -0.50$ ($p=0.05$) | $r = -0.39$ ($p=0.09$) |

A multiple linear regression analysis was performed expressing PRSH as a function of popliteal height and desk height (Equation 1) revealing that desk height and popliteal height together accounted for 36% of the variation in PRSH.

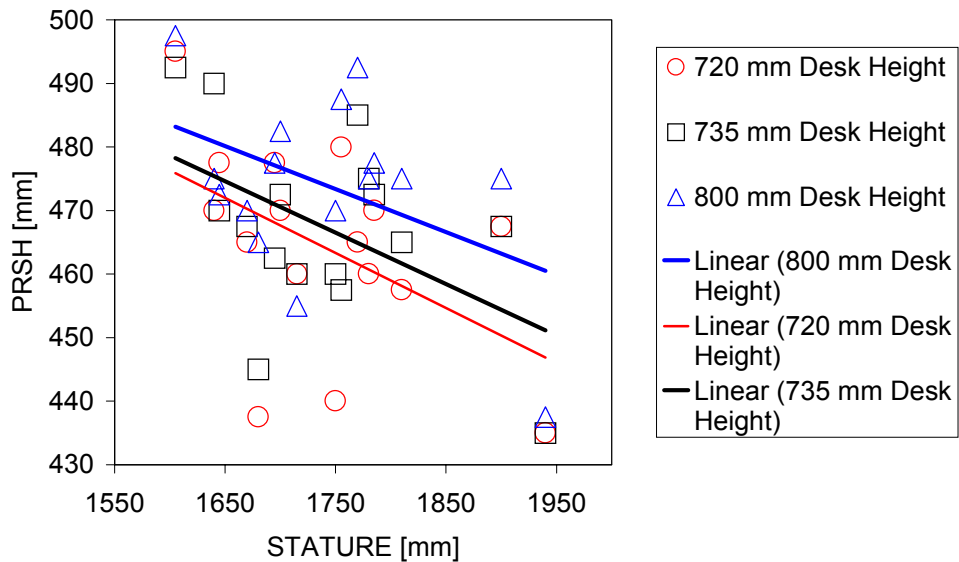
$$\text{PRSH} = 461 - 0.226 \times \text{Popliteal Height} + 0.136 \times \text{Desk Height} \quad (R^2=0.36) \quad (1)$$

Where all measures are in mm.

The preferred desk height of the eight students who also adjusted their desk height averaged 751 ± 25 mm with a corresponding PRSH of 446 ± 15 mm.



a



b

Figure 3.2. a). Popliteal height versus PRSH for each desk height (800, 735 and 720 mm). The coefficients of determination (R^2) for the three desk heights were 0.29, 0.31 and 0.36 respectively. b). Stature versus PRSH for each desk height. The coefficients of determination (R^2) for the three desk heights were 0.19, 0.24 and 0.24 respectively. Symbols represent observed data. Regression lines representing fitted data are shown although testing for parallelism did not demonstrate significant differences between the regression lines in either graph 3.2a or 3.2b.

Discussion

Time necessary for preference

Zacharkow (1988) suggested that the time necessary for assessing chairs should correspond to the duration of usual use. Mandal (1984), however, used a brief duration of sitting to determine the users' preferences. No significant difference was found between the PRSHs in the thirty minute simulated classroom situation and when the students found their PRSH at their own pace. A student determining his or her preference with reference to the required tasks without imposing a mandatory time period is thus a valid means of assessing preferred seat position.

Preferred rear seat height

The range of the average PRSH for students using the three desk heights in this study expressed as a seat angle (-1.1 to +1.7 degrees) is higher than the range of seat angles of zero to -5 degrees proposed by Australian Standards (1995). The averages of PRSH (444 to 454 mm) are, however lower than a rear seat height of 517 – 519 mm that would correspond to the average popliteal height suggested by Noro (1994) or the 30% of stature as recommended by Mandal (1984). The conditions in the current study were designed to approximate the constraints placed on chair design for use in a school setting by predetermining the height of the front of the seat according to the popliteal height of the target population rather than by predetermining other aspects of the design such as the seat angle. The results of this study are therefore intended to be directly applicable to the design of the largest size of school chairs as used in Years 11 and 12.

Factors affecting preferred rear seat height

The studies by Mandal (1984) and Noro (1994) each used a different constant seat angle and found subjects' preferred heights of the front of the seat to center around their popliteal heights. Taller people tended to choose higher seat heights and shorter people tended to choose lower seat heights suggesting that people of different sizes prefer a similar range of postures if the seat angle remains constant. The finding in the current study using chairs with a fixed front seat height that taller students or those with longer popliteal heights selected a lower PRSH demonstrated an interrelationship between seat height and seat angle. When the height of the front of the seat was predetermined, it was no longer physically possible for people with different shod popliteal heights to sit with their legs and trunk in the same postures. Different size subjects in the current study were thus required to adjust a chair that could not be made to conform to the same proportions in relation to each subject.

The correlation between stature and preferred seat height ($r = 0.52$) found by Noro (1994) was of similar magnitude, but opposite direction to that found in the current study. Noro (1994) suggested that the variation in postures preferred by different individuals of similar size accounted for the low correlation. Although the configurations of the chairs were different, the similarity between the degree of variation found by Noro (1994) and by the current study could also be accounted for by individual variations in preferred postures.

Postures which can occur with 5th and 95th percentile stature students in the size chair recommended for their age group, are shown in Figure 3.3. Taller students or those with higher shod popliteal heights may sit with more extended knees as shown in Figure 3.3 or with increased hip flexion compared to smaller students when sitting in the same size chair.

Yasukouchi and Isayama (1995) and Chapter 2 of this thesis describe how increased hip flexion and / or knee extension increase torques acting on the pelvis to rotate the pelvis posteriorly, thus affecting lumbar posture. In the absence of any other forces under these conditions, the pelvis will rotate posteriorly and the trunk will either be more reclined or the lumbar spine more

flexed. Alternatively, other forces – either in the form of active muscle contraction or forces from the chair acting on the pelvis – must balance the torques acting on the pelvis. The taller student can reduce these torques by sliding forward on the seat and reclining the trunk. Alternatively, the lower rear seat height selected by taller subjects in the current study may reduce the degree of knee extension thus reducing the torques acting to rotate the pelvis posteriorly. The choice of smaller (or more negative) seat angles by taller students may, therefore be a means of reducing the torques acting on the pelvis and thereby reducing the effort necessary to maintain a sitting posture.

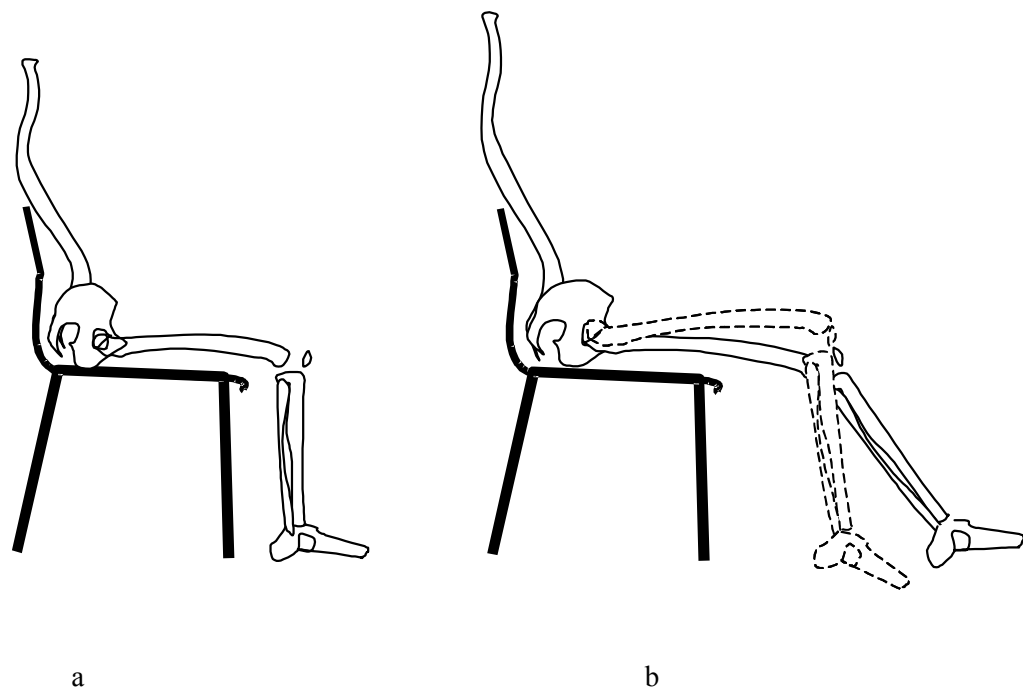


Figure 3.3. Extremes of size students using the largest size Australian school chair. Fifth percentile (a) and 95th percentile (b) students (Sebel Furniture 1995) in size school chair recommended for Year 11 students (Australian Standards 1995).

Zacharkow (1988) discussed findings from various studies that a reduction in the percentage of students able to reach their toes in a sit-and-reach test peaked in the mid teenage years. A combination of decreased leg flexibility and increased height may explain not only the lower PRSH of the taller students, but also the common, although anecdotal, observation of more slumped postures adopted by taller students.

Although students appeared to choose higher seat heights when using higher desks, no significant differences were detected between the relationships between stature or popliteal height on PRSH for the three desk heights. Sashaku (the vertical distance between the desk and seat) as a function of sitting height is a Japanese concept originally proposed in 1893 in relation to school furniture (Cho 1994; Noro 1994). According to the principle of Sashaku, for a given desk height, taller students would be expected to choose lower rear seat heights as found in the current study. If PRSH corresponded to the principle of Sashaku however, a change in desk height should also result in a change in PRSH of the same magnitude. In the current study the change in PRSH for a 80 mm change in desk height (720–800 mm) was only 10 mm, rather than the 80 mm predicted by Sashaku.

Furthermore if the height of the desk in relation to the student's arms or head were the more important factor influencing PRSH, stature (as it relates more closely sitting height than does popliteal height) would be expected to demonstrate a stronger correlation than popliteal height with PRSH. The stronger correlation between popliteal height and PRSH suggests that the PRSH is more influenced by what occurs below the level of the seat than above it.

Limitations

There are several reasons why the results of the present study should be interpreted carefully. Firstly, students of different ages have different patterns of posture (Schroder, 1997) and different physical proportions (Pheasant, 1992; Greil, 1997). Results of the current study cannot therefore be directly applied to students of different age groups. Secondly, only three discrete horizontal desk heights were assessed in the current study. The assessment of other desk heights

or of sloping desks as recommended by Mandal (1984 and 1994) and Zacharkow (1988) is required to more fully understand the factors underlying student choice of PRSH.

It is also known that the contour of the seat as well as seat angle and seat height can influence seated postures (Graf, Guggenbuhl and Krueger, 1993). Although Noro (1994) used padded, upholstered seats, neither Mandal (1984) nor Noro (1994) specify the seat contours used in their studies. Since the seat contour may affect the PRSH, the results found in this study can only be taken as approximations if applied to other seat shapes.

Finally, the five star bases used in the experimental chairs in the current study do not have the open space under the seat between the chair legs as occurs with most school chairs. Thus some postures such as students tucking their feet under chair or hooking their feet behind the legs of the chairs which are possible in most school chairs were less likely in the experimental chairs than in most school chairs.

Conclusions

Assessment of preferred seat position by students was the same using a brief adjustment period or an adjustment period corresponding to their usual classroom usage. It is therefore not necessary for students to take longer than the time necessary for them to determine their preferences to assess appropriate seat positions.

If it is accepted that students should be able to have their feet flat on the floor while sitting on school chairs and the height of the front of the seat of the largest size Australian school chair should be 445 mm, the recommended height of the rear of the seat is 444 to 454 mm (a seat angle of between -0.2 degrees and $+1.7$ degrees). The preferred rear seat height of students was dependent on the student's popliteal height and could be expressed as a function of the student's popliteal height and the desk height being used at the time.

4

Seat contours of Year 11 High School Students

The weightbearing buttock contours of 16 Year 11 students were measured in five representative postures in a seat position determined in Chapter 3. A device was designed and constructed to perform these measurements using an interface intended to evenly distribute pressure gradients. Anterior-posterior (AP) and lateral profiles were extracted from the contours. Four vertical and two horizontal dimensions were taken on each profile. The profile dimensions were analysed to determine any systematic variations related to posture, gender, mass or stature which may assist in the design of future school chair seats. The data showed consistent patterns in the general shape of both the AP and lateral profiles. Five out of the six profile dimensions were significantly different for males and females. In contrast only one dimension for one pair of postures demonstrated significant differences.

Introduction

Sitting in school chairs has been related to a high incidence of discomfort in school students (Evans, Collins and Stewart, 1992; Goodman & McGrath, 1991) and is also believed to affect students' mood (Haruki & Suzuki, 1994), attention and performance (Linton, Hellsing and Akerstedt, 1994; Vercruyssen & Simonton, 1994). The most important factor in overall sitting comfort affected by the chair is considered to be posture with the comfort of the seat surface second in importance (Kamijo, Tsujimura, Obara, and Katsumata, 1982). The contours of the front and back portions of the seat influence sitting posture (Chapter 2) and the whole of the seat contour affects seat comfort (Hertzberg, 1972). The contour of the seat thus affects the two most important factors influencing the comfort of a chair.

Although not specific to school seating, several types of contours of the front of the seat have been proposed to improve sitting posture. One type of contour consists of a horizontal region under the pelvis with the front of the seat inclined forward as proposed for sewing machinists (Yu & Keyserling, 1988) and office workers (Graf et al., 1993) which is meant to assist in maintaining a lumbar lordosis by allowing the thighs to slope downward while still providing a stable base for the pelvis. A second type of contour which has been proposed for wheelchair seats (Jay, 1994), office chairs (Gregory, 1987) and automotive seats (Sperr, 1985) is effectively a raised area in front of the ischial tuberosities to assist good posture by preventing the pelvis from sliding forward on the seat. A raised central portion of the front of the seat as occurs in horse saddles has also been proposed as a means of reducing the tendency for the pelvis to slide forward (Gale, Feather, Jensen, and Coster, 1989).

A raised contour at the rear of the seat as occurs on horse saddles has been advocated to assist posture for office chairs (Gale et al., 1989). Such a contour is intended to encourage a desirable lumbar lordosis by maintaining the pelvis in an anteriorly rotated position. A raised contour at the rear of the seat however is considered undesirable due to a tendency of the contour to slide the occupant forward on the seat producing a flexed lumbar posture (Bennett, 1928). The

contours in front of and behind the ischial tuberosities thus have different but potentially interrelated effects on seated postures.

Unlike the effects of seat contour on posture which are different for different regions of the seat, the effects of seat contour on seat comfort or discomfort appear to be similar for all parts of the seat (Sember, 1994). A reduction in nutrient supply to the buttocks is responsible for seat discomfort and when more severe and in a disabled population with reduced sensation also produces pressure sores. This reduction in nutrient supply appears to be related to tissue distortion which in turn appear to be more related to pressure gradients rather than peak pressures as previously thought (Gross, Goonitilleke, Menon, Banaag, and Nair, 1994).

The contour of the buttocks and posterior thighs (buttock contours) have been measured for specific individuals or populations and used to improve seats for pilots (Hertzberg, 1972), automobiles (Yamazaki, 1992), sewing machinists (Yu & Keyserling, 1988) and wheelchair users (Brienza, Chung and Brubaker, 1991; Springle, Faisant and Chung, 1990) but apparently not for school students. In each of these applications the contours were measured for only a single task-specific posture, however students in school chairs use a variety of postures including sitting forward when writing and sitting back when watching or listening (Schroder, 1997). Since buttock contours and pressure distribution have been found to be different with different postures (Henderson, Price, Brandstater and Mandac, 1994; Hertzberg, 1972; Hobson, 1992; Kernozek & Lewin, 1997; Koo, Mak and Lee, 1996; Shields & Cook, 1992), data on the buttock contours of school students in a representative sample of postures would be expected to be more useful for designing improved school seats than data on only a single posture.

The task of measuring buttock contours is complicated by the fact that the interface used in the measurement affects the contour to be measured. Thus buttock contours measured by different means may yield different results. Non weight-bearing buttock contours had been thought to adequately represent weight-bearing contours by assuming an even distribution of pressure and assuming that the buttocks behave according to a hydrostatic model (Waku, Terauchi and

Sakamoto, 1988). Unfortunately not only are non-weightbearing buttock contours different from weightbearing contours (Sember, 1994), but the weightbearing contours are also affected by the contour and characteristics of the buttock/seat interface (Koo et al., 1996). Since an even density of pressure gradients appear to be the most important factor in seat comfort (Gross et al. 1994) a measurement of seat contours using an interface which provides an even distribution of pressure gradients is required for contour data collected to be relevant to seat comfort.

A number of methods have been used for measuring buttock contours including passive methods of direct moulding, displacement of a grid of spring-loaded plungers (Brienza, Chung and Brubaker, 1991) and displacement of a grid of points on the surface of a block of foam (Springle, Chung and Brubaker, 1990a). In addition to these passive systems, active systems have been advocated which mechanically adjust the seat contour to equalise pressure (Brienza, Chung, Brubaker and Kwiatkowski, 1993) or even adjusted the contour such that the relative pressure at each point was inversely proportional to the overlying tissue stiffness (Brienza et al., 1996).

In the current study, the weightbearing buttock contours of 16 Year 11 students were measured in five representative postures. A device was designed and constructed to perform these measurements using an interface intended to evenly distribute pressure gradients. The purpose of these measurements was to determine characteristics of buttock contours across the population and determine any systematic variations in contours which may be related to posture, gender, mass or stature which may assist in the design of future school chair seats.

Methods

Subjects

Following approval of the study by the Griffith University Human Research Ethics Committee, the first 16 students in Year 11 (average age 16 years) at a local private high school who volunteered participated in the study. The students were dressed in their usual school uniforms including shoes. Informed consent was obtained from the students, their parent or guardian and a representative of the school prior to participation in the study. The stature of the subjects (six male and ten female) was measured to the nearest 5 mm using a stadiometer (mean 174 cm, SD= 9 cm). Body mass was measured to the nearest kilogram using a spring scale (mean 60 kg, SD= 9 kg).

Apparatus

An experimental chair was constructed consisting of a contour measuring device (bumograph) in place of the seat and a moulded plastic backrest from a commercial school chair (DuraPos size 6, Woods Furniture, Richmond Victoria) mounted on a commercial office chair mechanism (Taskmaster, Richard Small Pty. Ltd. Melbourne, Victoria) and five star base (mounted on glides rather than the usual castors) (Fig. 4.1).

The bumograph was constructed of a slab of high density ILD 45 polyurethane foam (EN38200 Dunlop Flexible Foams) 400 mm x 400 mm x 75 mm. A grid of 96 sensors (compared with 64 points used by Springle et al., 1990a) were distributed with a greater density in the regions of smaller radii of curvature (under the ischial tuberosities) and a lesser density in the regions of larger radii (under the thighs) in the pattern as shown in Figure 4.2a. To minimise distortions of the contour from forces resulting from tension or shear of the foam, a pattern of 10 mm deep vertical cuts were made into the surface of the foam such that one cut separated each of the points on the grid from its neighbours. Each sensor consisted of a 25 mm domed roofing washer on the surface of the foam connected by a bicycle cable passing through a vertical hole to a linear potentiometer (RSAON1119 ALPS Electric Co., Ltd. Tokyo) mounted on a frame below.

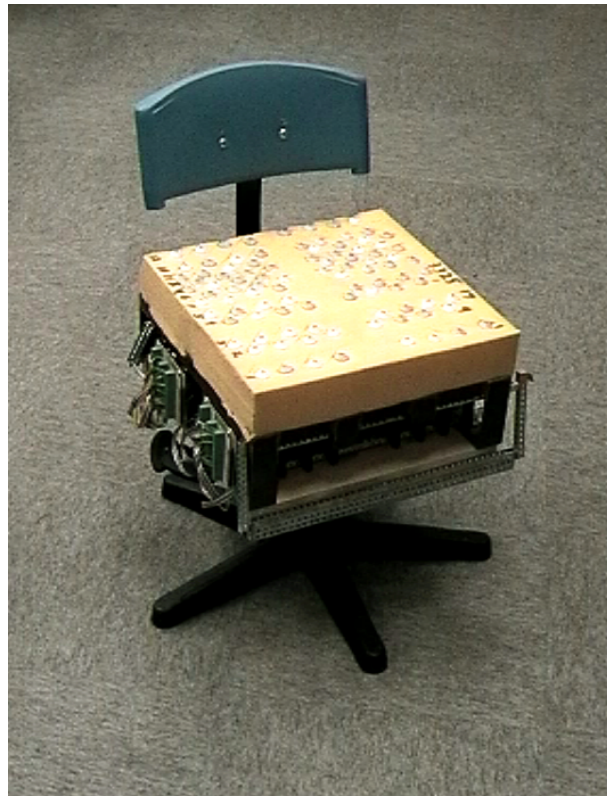


Figure 4.1. Bumograph mounted on experimental chair.

The potentiometers operating as voltage dividers were electrically isolated from mains power and multiplexed using purpose-built circuitry connected to a desktop PC through a DAQ card (P1200 National Instruments). A customised software program was used for calibration, data acquisition and storage of displacement data for the 96 points (Labview V 3.5 National Instruments). The grid of displacements from the 96 sensors were later interpolated using a method of least squares to a 35 by 35 cm surface contour containing a grid of points spaced at 10mm centres (Matlab version 5.3). This interpolated grid of displacement values was used for subsequent analyses.

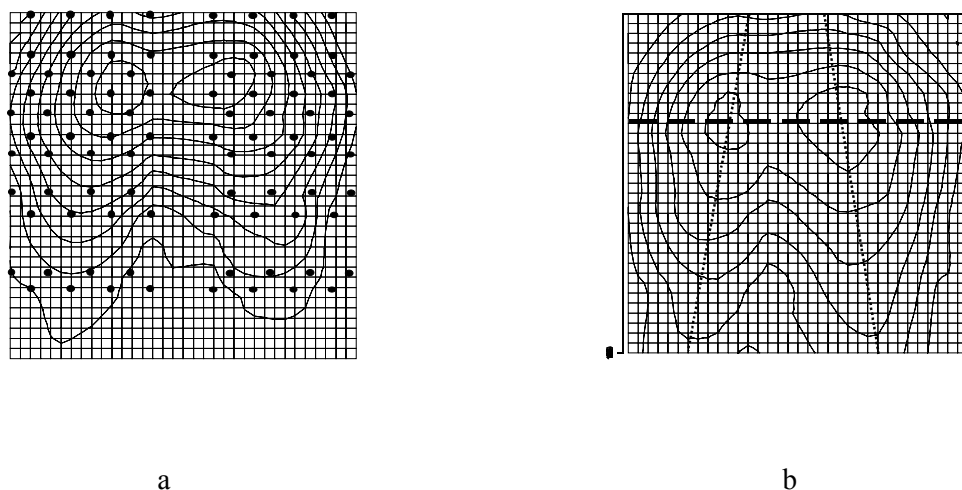


Figure 4.2. Typical contours of a male (a) and a female (b) student during keyboard posture. Contour lines are at 5 mm intervals and the intersections of the gridlines represent the extrapolated points. The dark points in 4.2a represent the positions of the sensors on the bumograph. The dotted and dashed lines in 4.2b represent the positions of the AP and Lateral profiles respectively.

Following calibration, assessing the accuracy of the device by taking measurements from all sensors at five displacements (10, 15, 20, 25, and 30 mm) resulted in a standard error for each vertical displacement of less than 0.1 mm. For assessing horizontal accuracy, the bumograph was indented by two spheres (100 and 125 mm diameter) with known distances between centres (100, 125, 150 and 200 mm.). Two trials were performed for each of the four horizontal distances. The standard error of the difference between the distances between centres of the spheres and the two deepest points on the extrapolated contour was 10.1 mm.

The bumograph was mounted on the experimental chair such that students would be in the position determined experimentally in Chapter 3 for Year 11 students (front seat height = 44.5 cm, rear seat height (30 cm from front) = 44.5-45.5 cm.). Preliminary trials suggested that the ischial tuberosities of students would compress the foam of the bumograph 3 to 4 cm (30-55% compression) and the posterior thighs at the front of the bumograph would compress the foam approximately 1 cm. The bumograph was positioned such that the height of the front was 45.5 cm and the height corresponding to the area under the ischial tuberosities (30 cm behind the

front of the bumograh) was 47.5 cm. The backrest was positioned as on the original chair school chair (centred 27 cm above the compressed seat and reclined by an angle of ten degrees from the vertical).

Data collection

The students sat on the experimental chair at a desk identical to their usual school desks

(horizontal desk surface 73.5 cm high) and were required to adopt, in random order, two trials each of five representative postures:

1. Keyboard - Using computer keyboard.
2. Sitback - Sitting reclined using backrest with feet in front of chair.
3. Situp - Sitting upright with feet flat on floor without using the backrest.
4. Slump - Sitting with lumbar and thoracic flexion without using the backrest.
5. Write – Writing.

Once the student had correctly assumed the test position, contour data was sampled at 0.5 Hz for a minimum of five seconds. The student was required to stand before assuming the next posture. One sample at least 2 seconds from either end of the collection period for each trial of each posture was used for subsequent analysis.

Data analysis

Three profiles were extracted to characterise each 35 x 35 point contour grid (Fig. 4.2b). An anterior-posterior (AP) profile on each side of each measured contour was taken through the line connecting the deepest displacement on the rear half of the seat (although the anatomical location of the deepest point was not confirmed, the deepest point on each side will be referred to as the ischial tuberosity) and the deepest point on the front edge on that side of the seat. One lateral profile was taken through the line connecting the ischial tuberosities on either side of the rear half of the seat.

Since the impressions for the various students and trials were in different positions on the bumograph and of different depths, the raw profiles were aligned prior to further analysis. The point 23 centimetres anterior to the ischial tuberosities was considered to be the front of the buttock contour as this was the most anterior data point available for all AP profiles. The raw AP profiles were aligned such that the point at the front of each profile and the ischial tuberosity of each profile corresponded horizontally and vertically. The AP profile for each subject for each posture was the average of the aligned AP profiles from both sides for the two trials for each posture. The raw lateral profiles were aligned vertically such that the ischial tuberosities on each side had a displacement of zero and horizontally such that the right ischial tuberosity of each sample corresponded. The lateral profile for each subject for each posture was the average of the aligned lateral profiles from the two trials for each posture. The average of the AP and lateral profiles were calculated by subject, posture and gender.

A total of six measurements were made on the AP and lateral profiles (Fig. 4.3). The vertical dimensions were:

1. Anterior height: The height at the highest point in front of the ischial tuberosity on the AP profile.
2. Posterior height: The height 8 cm posterior to the ischial tuberosity on the AP profile.
3. Lateral height: The height 10 cm to the right of the right ischial tuberosity on the lateral profile.
4. Intertuberosity (IT) height: The height at the highest point between the ischial tuberosities on the lateral profile.

The horizontal dimensions were:

1. Anterior distance: The distance between the ischial tuberosity and the highest point in front of the ischial tuberosity on the AP profile.
2. IT distance: The distance between the right and left ischial tuberosities on the lateral profile (note: the IT distances were measured for each trial prior to averaging as the left ischial tuberosity would not have a zero displacement in the average profile when the IT distances for the two trials were unequal).

ANOVA was used to determine the effect of gender and posture on the dependent variables of the profile dimensions (anterior height, posterior height, lateral height, IT height, anterior distance, and posterior distance). A post-hoc Scheffe test was used to determine specific differences between groups. Pearson correlation coefficients were used to determine if significant correlations existed between mass or stature and the dependent variables of the profile dimensions. Significance levels were set to $P < 0.05$ for all statistical tests.

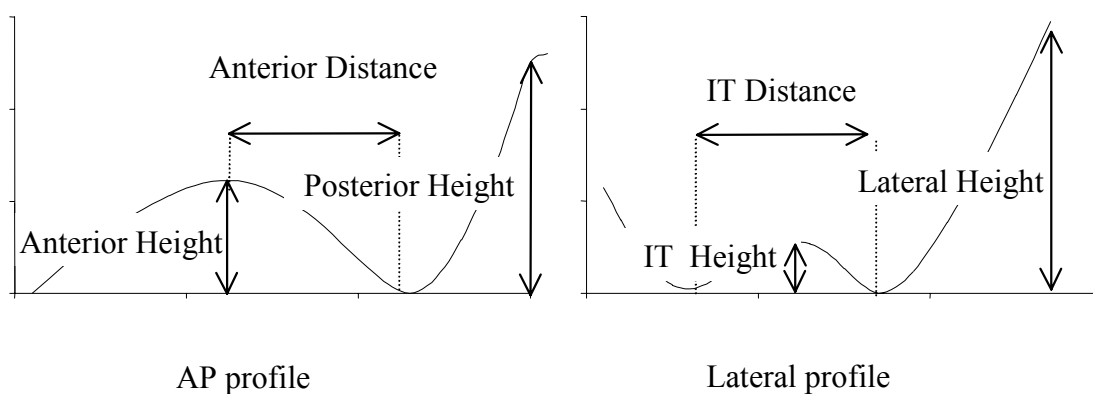


Figure 4.3. AP and lateral profiles showing the relationship between the profiles and the dimensions used to characterise the profiles. The four vertical dimensions are the anterior height, posterior height, lateral height, and IT height. The two horizontal dimensions are the anterior distance and the IT distance.

Results

The AP and lateral profiles (Fig. 4.4) were found to have common characteristics. The AP profiles were a sigmoid shape rising between the front of the seat and the ischial tuberosities and again behind the ischial tuberosities. The lateral profiles were a 'W' shape rising between and on either side of the ischial tuberosities.

Comparison of the profiles for males and females showed several significant differences (Fig. 4.4b and Table 4.1). The males had larger displacements than the females for all vertical profile dimensions (anterior height, posterior height, lateral height and IT height). One horizontal profile dimension, anterior distance, was significantly less for males than females.

Fewer significant differences were found between postures than between genders (Fig. 4.4c). The AP profiles were similar across the five postures. The IT height was the only dimension to demonstrate significant differences between the five postures ($F= 4.6$, $P < 0.01$). Post hoc (Scheffe) tests revealed that only two of the postures (keyboard and sit back) were significantly different.

Although there were significant correlations between both mass and stature and some profile dimensions, no overall pattern emerged (Table 4.2). Mass demonstrated significant positive correlations with two horizontal dimensions (anterior distance and IT distance) and a significant negative correlation with one vertical dimension (posterior height). Stature demonstrated significant positive correlations with the horizontal dimension of IT distance and the vertical dimensions of anterior height and lateral height.

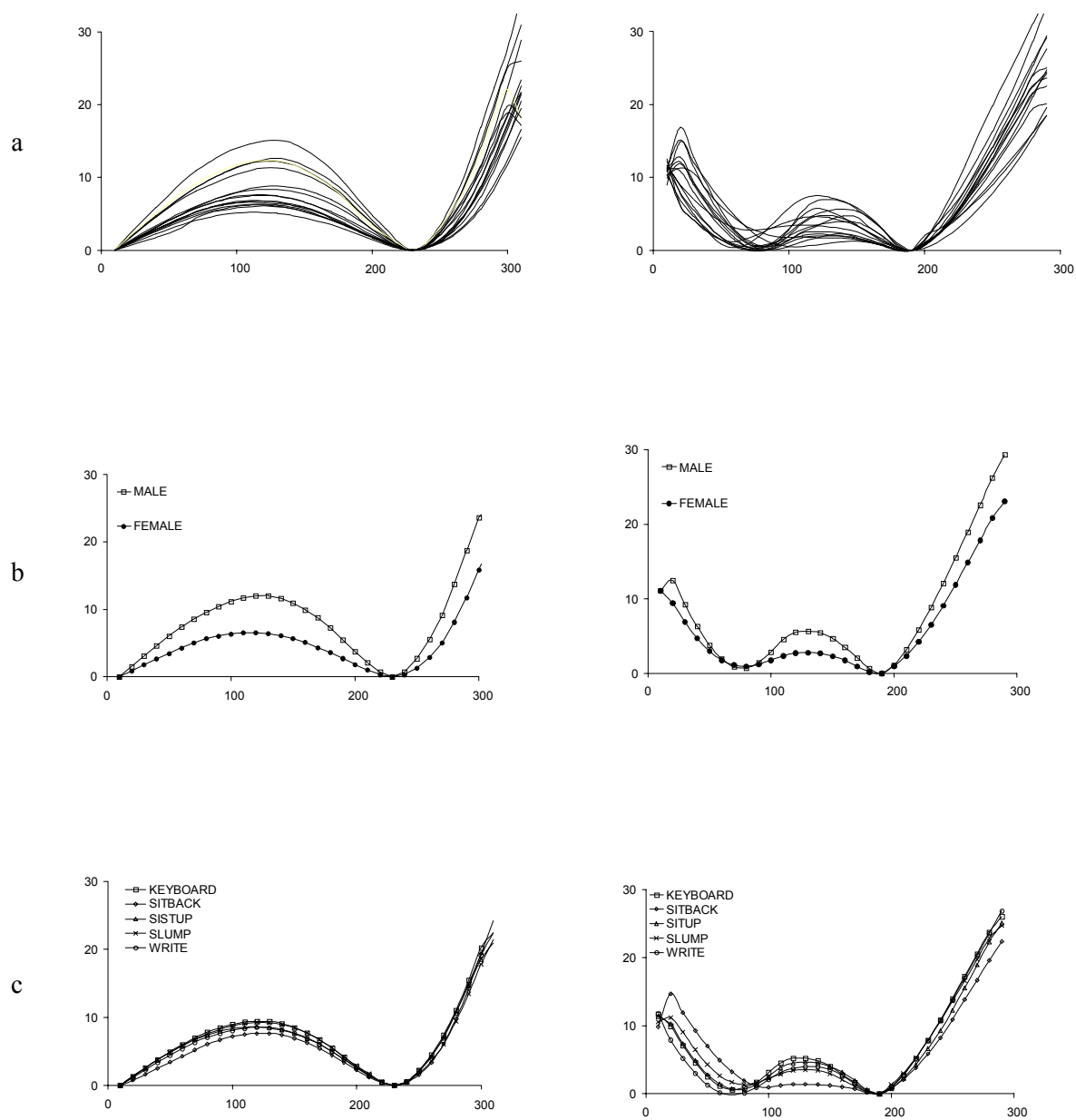


Figure 4.4. AP profiles and Lateral profiles grouped by subject (a), gender (b) and posture (c). Vertical and horizontal distances in mm.

Table 4.1. Mean values (SD) of profile dimensions grouped by gender.

| Group | Anterior Height (mm) | Posterior Height (mm) | Lateral Height (mm) | IT Height (mm) | Anterior Distance (mm) | IT Distance (mm) |
|---------------|----------------------|-----------------------|---------------------|----------------|------------------------|------------------|
| Male (SD) | 12.1 ** (2.5) | 23.6 ** (5.1) | 29.7 ** (5.5) | 6.2 ** (2.4) | 10.5 ** (0.7) | 11.1 (1.1) |
| Female (SD) | 6.8 ** (1.2) | 16.3 ** (4.3) | 22.8 ** (5.6) | 3.7 ** (2.3) | 11.3 ** (1.0) | 10.9 (1.6) |
| Combined (SD) | 8.8 (3.1) | 19.0 (5.8) | 25.4 (6.5) | 4.7 (2.6) | 11.0 (1.0) | 11.0 (1.5) |

**Indicates significant difference between males and females ($P < 0.01$)

Table 4.2. Pearson correlation coefficients between the anthropometric measures of stature and mass and the profile dimensions.

| Anthropometric measure | Anterior height | Posterior height | Lateral height | IT height | Anterior distance | IT distance |
|------------------------|-----------------|------------------|----------------|-----------|-------------------|-------------|
| Mass r | -0.022 | -0.339 ** | 0.047 | 0.105 | 0.238 * | 0.231 * |
| Stature r | 0.301 ** | -0.009 | 0.132 | 0.244 * | 0.172 | 0.298 ** |

* $P < 0.05$, ** $P < 0.01$

Discussion

The current study employed a device for measuring buttock contours consisting of a grid of sensors on a block of polyurethane foam. The pressure between a point on a block of polyurethane foam and its indenter approximates a linear function up to 60% compression of the foam (Brienza, Lin and Karg, 1999; Springle, Chung and Brubaker, 1990b). Thus the indenter into the block of foam would be expected to be subjected to pressure proportionate to the magnitude of displacement. Although previous studies (Springle et al., 1990a) used an even distribution of points, an advantage of using polyurethane foam is that the grid of sensors can be distributed to provide greater or lesser detail as required in different regions of the seat. Further advantages of using polyurethane foam are its durability, ease of fabrication and low cost. A disadvantage of polyurethane foam is that although it exhibits a linear relationship between force and displacement for the relevant range of compression, it is 4 to 5 times stiffer in shear and ten times stiffer in tension than compression (Springle et al., 1990b). When a non-planar indenter such as the buttocks compresses the foam this stiffness in shear and tension could distort the measured contour by creating significant forces other than those resulting from compression. Vertical slits in the surface of the foam were intended to reduce the distortions in measured contours resulting from shear or tension of the foam.

The current study was undertaken to collect data on buttock contours of students from which more effective school chair seats could be developed. The data showed consistent patterns in the general shape of both the AP and lateral profiles. The buttock portions of the contours resembled spheres elongated towards the thigh as opposed to symmetrical ball or football shapes previously described from non-weightbearing contours (Waku, Terauchi and Sakamoto, 1988). The vertical dimensions show much greater variation between subjects than the horizontal dimensions indicating that the main differences between subjects are in the depths of the profiles.

The AP profiles in front of the ischial tuberosities in the current study resembled the seat profiles proposed by Yu and Keyserling (1988) and Graf et al. (1993). Yu & Keyserling (1988) measured the non-weightbearing profile of the posterior thigh of seated subjects and proposed an angled seat profile with a horizontal surface under the ischial tuberosities and the front 15 cm inclined by 24 degrees. Subjects studied by Graf et al. (1993) preferred a similar angled seat profile (front 18 cm inclined by eight degrees) to a more traditional seat shape. The recommendations of both studies differed from the contours measured in the current study in that neither advocated a raised profile behind the ischial tuberosities.

All profile dimensions with the exception of IT distance were significantly different between males and females. The greater height for all vertical measures for males than females is consistent with findings by Springle et al. (1990a) and has been related to gender differences in the shape of the pelvis and body fat distribution. The shorter anterior distance for males may simply be the result of the deeper contours produced by males than the females. When measured on the pelvis the intertuberosity distance is greater for females than for males (Zacharkow, 1988). The size of the difference (approximately 1 cm) however is smaller than the resolution of the bumograph and may explain why possible differences in IT distance were not detected in this study.

Differences in the profiles were expected in relation to differences in posture (Kernozeck & Lewin, 1997; Liu & Bodnar, 1992; Reinecke, Weisman and Pope, 1994), mass (Waku et al., 1988), and possibly stature. The only observed difference in relation to posture however was a lower IT height for the sit back posture compared with keyboard posture. The lower IT height for the sitback posture is consistent with weight-bearing occurring on the posterior pelvis and sacrum rather than on the ischial tuberosities as with the more upright postures. Although several correlations exist between the anthropometric measures (mass and stature) and the profile dimensions, no recognisable pattern was observed.

In conclusion buttock contours of Year 11 students of different genders and in different postures are surprisingly similar. The significant differences in buttock contours being related to gender, mass, and stature rather than posture suggests that, at least for able bodied school students, it is important to assess the buttock contours of a range of subjects of both genders, but not necessary to assess the buttock contours in a variety of postures.

The measurements of buttock contours collected in the current study provide a database that can be used in the design of future school chair seats. A simple average of the contours of a population is unlikely to provide the best fit for the population (Melzer & Moffitt, 1996). A challenge for future research will thus be to determine a seat contour to achieve a best fit between the relatively rigid surface of a school seat and the buttock contours of a student population while still allowing or even supporting the postural changes necessary in the school setting.

5

Summary and conclusions

“Alls Well that Ends Well”

Summary

William Shakespeare recognised the difficulty of having one chair to fit different shapes and sizes when the clown in *Alls Well that Ends Well* (Act II, Scene 2) described having one answer to serve all questions as being ‘like a barber’s chair that fits all buttocks; the pin-buttock, the quatch-buttock, the brawn buttock, or any buttock.’ In the school setting one chair not only needs to fit students of different shapes and sizes, but must also accommodate the students in a variety of postures. The central question addressed in the present study is therefore how one size of school chair can optimally serve its function for a population of students in a variety of postures.

Specifically the aim was to determine the appropriate seat position for the largest size school chair for Australian schools and to develop a database of seated buttock contours of school students who use this size chair. In order to accomplish this aim it was first necessary to understand the mechanics of sitting and the relationship between the occupant and the chair.

A simplified passive model of the seated human body in the sagittal plane consisting of four rigid links (feet and shanks, thighs, pelvis and trunk) was used to explore the mechanical relationships between a chair and its occupant. Using this model it was demonstrated that biomechanical factors including the angle at the joint between each pair of links (knees, hips and lumbar spine), the relative position of the centre of gravity of the trunk relative to the base of support of body on the seat and the characteristics of the seat itself all influence the posture of the occupant of the chair.

The height of the front of the seat, the seat depth and seat width for the largest size Australian school chair are well documented in both the Australian Standards and literature from the industry. The appropriate configuration of a chair including design features such as seat and backrest angles and contours to suit a particular population is related to biomechanical factors affecting the user’s posture in a chair and is more difficult to determine. Although all of the

biomechanical factors and therefore the design features are interrelated, it was necessary to investigate one design feature at a time in order to eventually build up to a complete chair design with the consideration of each feature building on the previous results. The first feature to be investigated in the current study was the position of the seat.

In order to determine the appropriate seat position, an experimental chair was constructed consisting of:

- A seat from the largest size commercial school chair mounted such that the height of the front of the seat was set at the recommended height and the rear of the seat (the seat angle) was adjustable.
- A backrest from the same size and model of commercial school chair mounted in the same position relative to the seat as on the commercial school chair.

Two groups of 16 Year 11 students adjusted the experimental chair to their preferred position. The first group adjusted the chair while using a single desk height during a 30 minute simulated classroom activity. The second group adjusted the experimental chair while using each of three desk heights taking only as much time as they required to find their preferred seat position.

The results indicated that:

- The duration of the adjustment period did not affect the preferred seat position.
- Students with a larger popliteal height and, to a lesser extent, taller students tended to prefer a lower rear seat height.
- The preferred seat position was between a seat with a slight forward inclination and a horizontal seat.

A group of 16 Year 11 students participated in a second experiment using a second experimental chair consisting of a device for measuring buttock contours mounted in the position determined in the first two experiments. The contours were measured twice in each of five postures representative of postures used by students in a school setting. Two anterior-

posterior and one lateral profile were extracted from each contour and six dimensions taken from each set of profiles. The results demonstrated:

- A similarity of the profiles across the five postures with only one of the six profile dimensions demonstrating a significant difference between one pair of postures.
- Gender had the greatest effect on the profile dimensions (females tending to have shallower, more rounded profiles) with five of the six profile dimensions demonstrating significant differences.
- Stature and mass each demonstrated small but significant effects on three of the six profile dimensions.

Conclusions

From the current study it can be concluded that:

- Chair design features such as seat and backrest position and contours are not independent in their influence on the posture of the occupant of the chair.
- The contours of the front and back of the seat each have distinct influences on the posture of the occupant.
- The appropriate angle for the largest size of school chair in Australia is between - 1.1 degrees and + 2.7 degrees.
- Students with shorter popliteal heights and students using higher desks had a higher preferred rear seat height (a more inclined seat).
- The seated buttock contours of Year 11 students showed very little variation across the five postures tested.
- The main differences that do exist in seated buttock contours of Year 11 students are related to gender and to a lesser extent mass and stature.

Directions for future research

Three regions of seat contours have distinct but interrelated influences on the function of a seat; the contour of the seat in front of the ischial tuberosities, the contour behind the ischial tuberosities and the lateral contour. The preferred seat position for Year 11 students was found in Chapter 3 of the current study. A single preferred seat contour in this position can be determined using a two-stage comparison of pairs incorporating combinations of the average, 5th and 95th percentiles of the front, back and lateral buttock contours found in Chapter 4. The best position and shape of backrest can then be determined for that seat configuration using a similar process to that used to determine the seat configuration.

A prototype chair can then be constructed and evaluated against school chairs currently available in Australia and against a design based on the work of Mandal which has been the subject of considerable research in Europe. If the chair proves superior to other available school chairs, the methodology can be repeated in future work for the other school chair sizes.

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