THE EFFECT OF DIFFERENT SEATING CONDITIONS, IN AIRCRAFTS, ON PASSENGER COMFORT AND THE USE OF CABIN SPACE

BY

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ABSTRACT

Although aircraft cabin design has improved over the years, passengers continue to complain about sitting discomfort whilst flying. These complaints are often centred on the cramped and restricted seating conditions. Whilst passenger comfort is important, in order for airline companies to attract and retain customers, it is also important to design for cabin space needs. Denel Aviation intends to build a South African Regional Aircraft (SARA) that will fly point-to-point, linking regional centres and intends to design aircraft seats that not only optimise passenger comfort, but which also save cabin space.

The aim of this investigation was two-fold. The first aim was to determine how aircraft backrest angle affected passenger comfort, ease of seat access, perceived restriction and legroom, with different seat pan angles and seat heights. The second aim was to determine whether passenger comfort was affected with the most preferred backrest angle for each seat pan angle and seat height. Determining how seat pan angle and seat height affect the preferred angle of the backrest was considered important as Denel intend to use aircraft seats with a non-adjustable backrest angle.

For this study, 80 participants were recruited from Rhodes University and the general Grahamstown population. The participants consisted of 40 males and 40 females and were not limited by race, ethnicity or culture. The participants were classified into two age groups; 18-30 years of age and 31-60 years of age. Participant stature, body mass, BMI and lower leg length was recorded to determine the effect these factors had on sitting comfort when the participants were seated in different seating conditions.

From the results obtained, it was found that, by altering seat height, seat pan angle, and backrest angle, passenger comfort can be optimised. Furthermore, it was found that certain combinations of seat height, seat pan angle and backrest angle are more beneficial with regards to saving aircraft cabin space. However, this means that a compromise needs to be found for SARA as passenger comfort needs to be optimised, whilst decreasing the use of cabin space to reduce costs.

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CHAPTER I
INTRODUCTION

BACKGROUND TO THE STUDY

Air transportation has become an increasingly popular mode of transportation. It has been projected by The International Air Transport Association (IATA) that global passenger departures are expected to rise from 2.3 billion in 2009 to 16 billion by 2050 (IATA, 2010; Hall *et al.*, 2013). Denel Aviation, the aircraft maintenance division of Denel, is a company that has identified this increase in demand, specifically on the African continent. Denel Aviation has been supporting the South African Airforce for 50 years and has expanded to provide increased support to the African continent and selected markets worldwide (Denel Aviation, 2015). Research has shown that only 17 out of more than 420 local airfields in South Africa form part of a scheduled airline service (Denel Aviation, 2014). As regional centres do not have sufficient demand to attract mainline services, Denel believes that this has created an opportunity for the development of an indigenous South African aircraft that can fly point-to-point, linking these regional centres (Denel Aviation, 2014). Denel is in the process of developing a South African Regional Aircraft (SARA); a turboprop, civil aircraft that can take-off and land on short airfields in regional centres (Denel Aviation, 2014; Wingrin, 2014). It is believed that SARA will not only fill a gap within the African aviation industry, but that it will also help in promoting economic growth, infrastructure development, tourism and job creation in rural and outlying areas (Campbell, 2014).

Due to the highly competitive nature of the aviation industry, it is necessary for airlines to differentiate from their competitors to attract and retain customers (Hall *et al.*, 2013). One of the main ways this is achieved is through meeting customer requirements, with passenger comfort and experience being typical value drivers (Hall *et al.*, 2013). Passenger comfort and experience are considered key variables relating to customer satisfaction and their willingness to use the system again (Vink, *et al.*, 2012; Hall *et al.*, 2013). Research has found that factors such as cleanliness of the aircraft interior, 'nice crew' and in-flight entertainment all affect passenger comfort (Vink *et al.*, 2012). However, of these factors, the most important is the

aircraft seat (Vink *et al.*, 2012). The aircraft seat is considered to be the main interaction point between the aircraft and the passenger throughout the duration of a flight (Schumm *et al.*, 2010). Therefore, it is essential to gain an understanding of this relationship, given that passengers are required to sit for prolonged periods of time, without much opportunity to vacate the seat and walk around (Dumur *et al.*, 2004). As a result, the aircraft seat needs to be optimised to improve the comfort of passengers during air transportation. Although passenger comfort whilst flying is an important aspect that needs to be considered, it is also necessary to design for affordability (Brauer, 2004). It is in the interest of airline companies to increase revenue by increasing the number of passengers that can fly at one time. This is often done by compromising seating standards, specifically by decreasing seat pitch - the distance from one point of a seat to the same point of the seat in front (Kremser *et al.*, 2012).

While decreasing seat pitch is more economical to the airline company, it is associated with an increase in passenger discomfort. This discomfort can be both emotional and physical in nature (Brundrett, 2001). Emotionally, passengers may experience increased stress and anxiety due to feelings of a lack of personal space (Brundrett, 2001; Tan *et al.*, 2009). Physically, passengers may experience restlessness and stiffness (Hinninghofen & Enck, 2006; Helander, 2010; Vink *et al.*, 2012). It is therefore the aim of this study to identify ways in which to optimise the use of cabin space, whilst providing the best possible passenger comfort, specifically with regards to SARA. Investigating other seating characteristics becomes important to gain an understanding of how these affect sitting comfort. Seating characteristics such as seat height, seat pan angle and backrest angle are all likely to play a role in determining passenger comfort whilst flying. It is also likely that these factors will interact to affect the amount of space needed for each aircraft seat. However, it must be noted that there will always be a trade-off between the use of space on the aircraft and the comfort of the passengers.

STATEMENT OF THE PROBLEM

Seat dimensions on aircrafts play a central role in determining passenger comfort whilst flying (Vink & Brauer, 2011). Although research to understand the relationship between aircraft seat design and passenger comfort exists (Tan *et al.*, 2009; Kremser *et al.*, 2012; Vink *et al.*, 2012), these studies have tended to focus

specifically on factors such as seat pitch and legroom as these are two of the main contributing factors to discomfort whilst flying. Cabin space on the aircraft is an important issue, both for the airline company and the passenger. However, no research can be found on how to utilise cabin space effectively while maintaining passenger comfort, specifically through the interaction between chair characteristics such as seat height, seat pan angle and backrest angle. While manufacturers may have studied these factors, they have not published for obvious reasons. This is particularly important as Denel aviation intends to use chairs with a non-adjustable backrest angle. Studying the interaction between these three factors will be important to determine how seat height and seat pan angle affect the preferred angle of the backrest, as well as how this combination will vary the amount of space that is needed for each chair and its' passenger. While there will always be a space-comfort relationship, whereby decreasing space needs will negatively affect passenger comfort, it is hoped that the relationship between seating characteristics will be better understood.

RESEARCH HYPOTHESIS

This study was conducted for two reasons. The first was to determine whether or not backrest angle affected the participants' ease of seat access, perceived subjective comfort, perceived restriction and space used for legroom at any of the given seat pan angles and seat heights. The second part of the study was to determine whether seat pan angle and seat height, at the preferred backrest angle, affected the participants' perceived subjective comfort.

CHAPTER II
REVIEW OF LITERATURE

INTRODUCTION

From research that has been conducted, it has been found that there are a number of factors related to the aircraft cabin that affect passenger comfort (Vink & Brauer, 2011; Han, 2013). Of these factors, it has been established that aircraft seats and seating arrangements contribute the most to passenger comfort and experience whilst flying (Richards & Jacobson, 1977; Vink *et al.*, 2012). Before comfort in aircraft can be discussed, it is important to first have a general understanding of comfort and discomfort.

COMFORT AND DISCOMFORT

The concepts of comfort and discomfort are not new ones, yet remain difficult to define, as there are many widely accepted definitions (de Looze *et al.*, 2003). Richards (1980) stresses that comfort is "the state of a person involving a sense of subjective well-being, in reaction to an environment or situation". On the other hand, Slater (1985) defined comfort as "a pleasant state of physiological, psychological and physical harmony between a human being and its environment". While there are varying definitions of comfort, it is accepted that comfort is a subjective phenomenon and is affected by many different factors (de Looze *et al.*, 2003). These are often separated into two categories; internal and external factors. Internal factors are dependent on the individual, their history of comfort and their current state (VInk & Brauer, 2011). The external stimuli that affect perceptions of comfort include factors such as smell, noise, visual input, temperature, pressure and movement (Vink & Brauer, 2011). The internal and external factors do not act in isolation but are rather interlinked. Together they create the perception of discomfort (Vink & Brauer, 2011).

Two main theories have been developed on how to measure comfort and discomfort. The first is that comfort and discomfort are two extremes on a continuum; two opposites on a continuous scale that range from extreme comfort, through a neutral state to extreme discomfort (Figure 1).

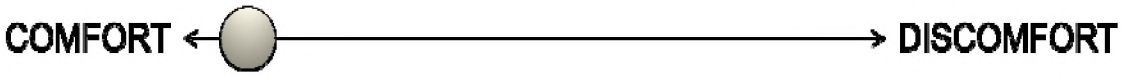

Figure 1: Linear definition showing comfort and discomfort on opposite extremes of a continuous scale (Openshaw, 2011).

Defining comfort and discomfort in this manner is often considered unsatisfactory from a scientific perspective as studies suggest that comfort and discomfort are affected by distinctly different variables (Helander & Zhang, 1997). The second theory is known as the de Looze model (Figure 2) and is currently the most comprehensive model that exists in literature thus far (Openshaw, 2011). The de Looze model states that comfort and discomfort are two different constructs with different sets of underlying factors (de Looze *et al.*, 2003). Promoters of this theory have conceptualised comfort as two discreet states; the presence of comfort and the absence of comfort (de Looze *et al.*, 2003). Here, comfort is simply defined as the absence of discomfort and vice versa (de Looze *et al.*, 2003), suggesting that comfort does not necessary entail a positive effect. Therefore, the absence of discomfort does not necessarily result in comfort (Vink & Brauer, 2011). From this, three conditions of comfort have been distinguished: 1) Discomfort; where the participant experiences discomfort due to physical disturbances in the environment; 2) No discomfort: the participant is not aware of the fact that there is no discomfort and 3) Comfort: the participant experiences noticeably more comfort than expected and feels comfortable (Vink & Brauer, 2011). The de Looze model specifies three main influences for comfort/discomfort assessment: the human, the product and the environment. This model suggests that the humans' physical composition, such as weight and physiological processes of skin temperature, muscle activation, and nerve conduction, can influence perceptions of discomfort (de Looze *et al.*, 2003). It is probable that interactions exist between the physical capacity and the physiological processes of the user (Openshaw, 2011).

Not only can comfort be influenced by physical and physiological factors, but it has been stated that emotions and expectations, along with the physical features of the product, can influence the individuals' perceptions of comfort (de Looze *et al.*, 2003). Physical features of the product include cushion thickness, contours, lumbar support, size and dimensions. Comfort and discomfort can also be influenced by the physical

environment. These include lighting and temperature, tasks being performed, as well as psychological aspects such as job satisfaction and interaction with colleagues (de Looze *et al.*, 2003).

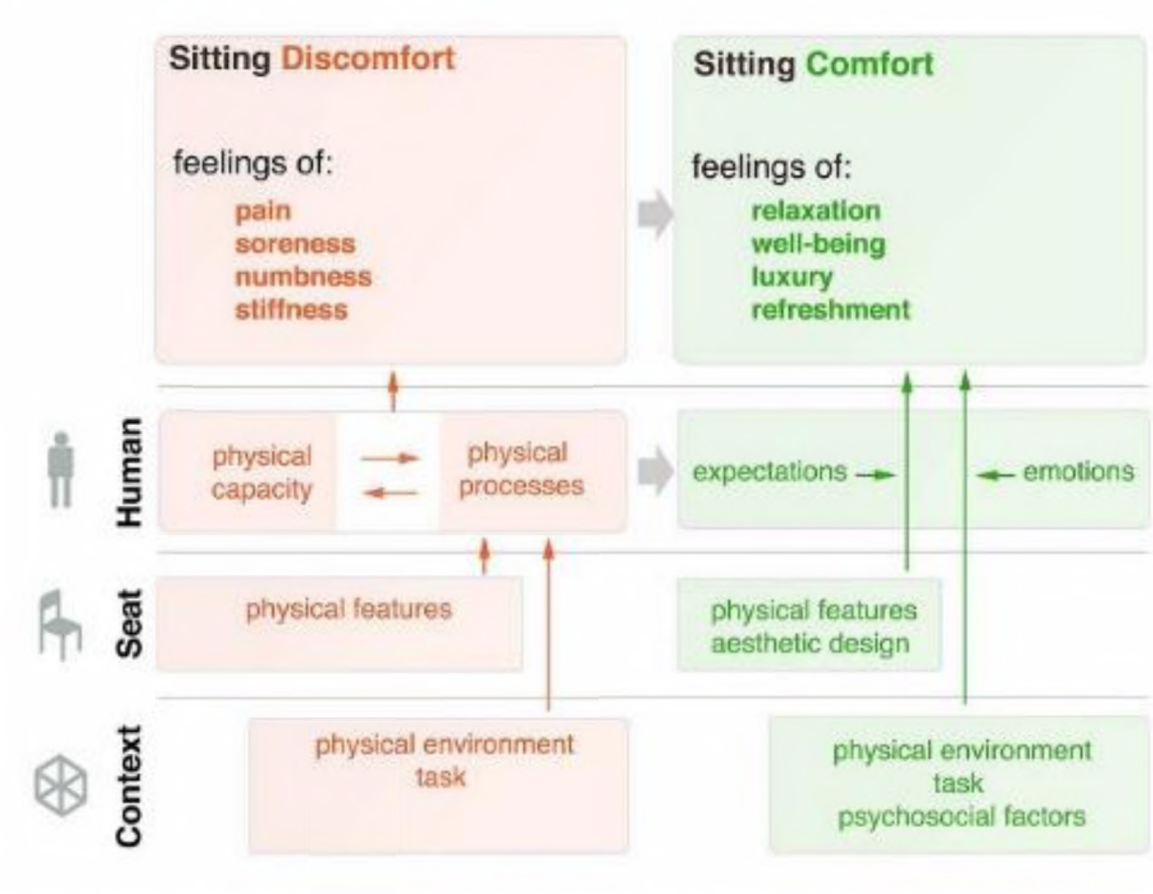

Figure 2: The de Looze Comfort Model showing the factors that affect comfort and discomfort (Openshaw, 2011).

AIRCRAFT COMFORT

The comfort experienced by passengers whilst flying is particularly important to improve for a number of reasons. Firstly, the comfort experience of passengers whilst flying is likely to impact on their decision to use that same airline company in the future, which in turn affects the competitiveness between aircraft companies (Dumur *et al.*, 2004). Secondly, a larger proportion of the World population is starting to use air transportation (Hiemstra-van Mastrigt, 2015). This means an increase in the number of elderly passengers and individuals with disabilities (Dumur *et al.*, 2004). Another factor that needs to be considered includes the global epidemic of increases in obesity (Puoane *et al.*, 2002; Lang & Froelicher, 2005). Obesity is a complex condition whereby excess body fat predisposes an individual to many

different health problems (Lang & Froelicher, 2005). There are a number of methods used to determine the weight status of individuals, with the most popular being that of body mass index (BMI) (World Health Organisation, 2000). BMI is a simple method of classifying whether an individual is underweight, overweight or obese and is defined as weight (kg)/height(m)^2 (World Health Organisation, 2000). The classification of individuals can be seen in Table 1 below.

Table 1: The classification of individuals according to BMI (World Health Organisation, 2000).

BMI	Classification
< 18.5	Underweight
18.5–24.9	normal weight
25.0–29.9	Overweight
30.0–34.9	class I obesity
35.0–39.9	class II obesity
≥ 40.0	class III obesity

Fleming *et al*. (2014) aimed to analyse trends in overweight and obesity from 1980 to 2013. The results showed that the worldwide prevalence of overweight and obesity combined increased from 27.5% and 47.1% for children between 1980 and 2013 (Fleming *et al*., 2014). With regards to men, the increase in prevalence increased from 28.8% in 1980 to 36.9% in 2013. The prevalence of obesity in women increased from 29.8% to 38% (Fleming *et al*., 2014). Within the African population, it has been found that, over a five-year period, there has been a dramatic increase in the prevalence of obesity within all age groups and ethnic groups (WHO, 2000). The proportion of obese men increased from 3.4% in 1897 to 5.3% in 1992. The proportion of obese women increased from 10.4% to 15.2% in the same time period (WHO, 2000). While rural adults who maintain a traditional lifestyle have gained little or no weight with age until fairly recently, the improvements in socio-economic status and rapid urbanisation have led to dramatic increases in the levels of obesity among some groups of black women. Approximately 44% of women living in the Cape Peninsula were estimated to be obese in 1990 (WHO, 2000).

The increasing trend of obesity world-wide is likely to impact the flying experience of passengers by raising the discomfort experience of these passengers whilst sitting. Not only is comfort an important aspect for the passenger but it could also lead to safer travelling conditions, as passengers who feel comfortable are likely to be less demanding to the aircrew (Dumur *et al.*, 2004). Increasing passenger comfort whilst flying is therefore an essential area of research. Dumur *et al.* (2004) explained that if airline passengers are asked how their comfort can be improved, the majority of passengers will make suggestions with regards to the aircraft seat. However, Dumur *et al.* (2004) state that this is not always a feasible option and that there are other factors involved that can contribute to increased comfort whilst flying. These authors devised four models in which these factors are explained.

The passenger bubble

The passenger bubble refers to the sense of privacy that passengers require whilst flying. It is important for passengers to have a space in which they feel isolated from disturbances and where they can partake in their own activities. These activities may include reading, working on laptops, writing, listening to music, watching a movie, eating and sleeping. To optimise the sense of privacy it is important for passengers to have individual facilities such as lights and sound so that the disruption of/to neighbours is minimised (Dumur *et al.*, 2004).

The health model

This model refers to the absence of nuisance, discomfort, potential health risks, as well as improving passengers' physical well-being. In order to achieve this, it is necessary for passengers to be pain-free whilst seated. They should be able to sleep comfortably and avoid feelings of boredom and stress. Passengers should also be able to leave their seats regularly, and should not be hindered by the seats and other forms of equipment when they do so (Dumur *et al.*, 2004).

The community model

Due to air travel being a form of public transport, passengers are exposed to a social-setting where they will communicate and share common experiences with other passengers. In this sense, comfort means that people travelling together have the opportunity to share a common experience. Passengers should be able to engage with fellow travellers, as long as it is not too obtrusive and invasive. Common

activities could include playing games, attending to children and leaning on each other whilst sleeping.

The aesthetic-economical model

This model refers to comfort as a passenger's perceptions of paying a reasonable price for being in an interesting, advanced and visually appealing environment. Traveling by air is not always affordable and passengers expect to enjoy the experience. This can be done by providing quality service, aesthetically pleasing environments and an attention to detail. However, there is a relationship between price and passenger expectations, with passengers demanding less on cheaper flights compared to a flight that is more expensive (Dumur *et al.*, 2004).

From the four models discussed above, it can be seen that passenger comfort is affected by the entire flying experience as a whole, from the price of the flight, to the amount of privacy on the aircraft. However, while these factors can be optimised to increase the comfort experience, research has shown the aircraft seat to affect passenger comfort the most and it is thought to be the area where the most improvements can be made (Richards & Jacobson, 1977; Vink *et al.*, 2012).

THE RISKS ASSOCIATED WITH SITTING

Seated postures are regarded as potentially unhealthy and have become increasingly associated with musculoskeletal complaints and disorders such as lower back, neck and shoulder pain (Kyung *et al.*, 2008). Due to increased amount of time spent sitting, sitting comfort has become an important aspect of everyday life, whether it be in the office, at home or in all forms of transportation. It is for this reason that the issue demands adequate ergonomic assessment and interventions (Kyung *et al.*, 2008).

The need for chair design, in general, has become more apparent, especially with the findings from two important studies (Helander, 2010). One of the first studies to look at chair design was conducted by Akerblom in 1948. This study investigated the EMG responses of the erector spinae muscles whilst sitting. A later study conducted by Andersson *et al.* (1979) assessed spinal intra-disc pressure during sitting. Both studies demonstrated that as an individual sits down, disc pressure increases by about 40-50% compared to standing (Akerblom, 1948; Andersson *et al.*, 1979). As a person moves from standing to sitting, the hip joint angle decreases from 180

degrees to 90 degrees (Helander, 2010). Approximately 60 degrees of the bending takes place at the hip joint, whilst the remaining 30 degrees is absorbed by the forward rotation of the pelvis, flattening the lumber curve (Helander, 2010). Flattening of the lumbar curve is not only associated with increases in spinal compression forces but is also associated with the deformation of the intervertebral discs (IVDs) (Kelsey, 1975). This occurs when the IVDs are compressed at the front and separated at the back, often leading to disc herniation (Kelsey, 1975). This is particularly problematic as there are no nerve endings in the IVDs, and so users are unaware of any increases in spinal pressure until it is too late and damage has already occurred (Helander, 2010). To reduce this disc pressure, the lumbar curve needs to be restored. This has led to the common practise of increasing the angle of the backrest to open up the hip joint angle to 110-120 degrees (Helander, 2010). However, it is not only important for chairs to provide support, but they also need to be physiologically satisfactory, as well as appropriate for any tasks and activities that the users are required to perform whilst sitting (Pheasant & Haslegrave, 2006).

Lower limb oedema

Prolonged sitting in fixed and constrained postures has been increasingly associated with lower limb oedema (Stranden & Kroese, 1998; Stranden, 2000). Lower limb oedema refers to swelling of the lower legs, ankles and feet and is particularly prevalent in passengers who sit in aircraft seats for prolonged periods of time (Noddeland & Winkel, 1988). Individuals who use air transportation are required to sit in small seats, with a seatbelt, their knees close to or touching the seat in front of them and their feet immobilized by luggage (Noddeland & Winkel, 1988). This can lead to swollen, aching legs and feet, and when combined with other lifestyle factors, can aggravate the risk of developing musculoskeletal complaints (Noddeland & Winkel, 1988; Dehart, 2003; Schobersberger *et al.*, 2007).

It has been stated that while sitting, less demand is placed on the circulatory system as the individual is essentially in a resting state and so heart rate is low. This decreases the amount of dynamic muscular activity (McArdle *et al.*, 2001). Decreased dynamic muscular activity causes capillary fluid filtration to exceed the removal of fluids by the lymphatic system (Strandon, 2000), which results in blood pooling in the lower legs (Canadian Centre for Occupational Health and Safety, 2008). Blood pooling is further aggravated by increased capillary hydrostatic

pressure caused by increased venous pressure from the pressure placed on the underside of the thighs by the seat pan (Stranden, 2000; CCOHS, 2008). Literature states that vein pressure is approximately 5mmHg when the feet are in a horizontal position. This increase to 70-80mmHg when an individual is in an upright position. The vein pump mechanism is able to reduce this pressure to 25-30mmHg whilst walking (Gardner & Fox, 1989). While sitting passively, vein pressure is only between 45-60mmHg and is determined by the height of the blood column from the feet to the heart (Stranden, 2000). While this is lower than when standing upright, it has been suggested that a constant venous pressure of 45-60mmHg with no breaks to lower it can have serious consequences (Todd *et al.*, 2007). The most serious consequence of sitting pressure is known as 'economy-class syndrome', a term coined by Symington and Stack in 1977, referring to a condition called deep vein thrombosis (DVT). DVT can occur in conjunction with pulmonary embolism (PE) and so doctors often refer to the two conditions as venous thromboembolism (Goldhaber *et al.*, 2004). DVT is a condition whereby a blood clot is formed in a vein, generally within the lower leg and thigh. In most cases the clot is small and symptom-free, gradually breaking-down by themselves (Broo, 2013). However, these clots can sometimes break away into the bloodstream where it travels to the lungs (Broo, 2013). This is known as pulmonary embolism. Once in the lungs, the clot can become lodged, causing chest pains, shortness of breath, and occasionally sudden death (Goldhaber *et al.*, 2004, Broo, 2013).

DVT is a topic of much debate. At a meeting held by the World Health Organisation, a consensus was reached agreeing that there is most likely a link between flying and DVT, even though the incidence is low and mainly involves passengers with additional risk factors for DVT (Nicholsen *et al.*, 2003). A number of studies have been conducted to determine the risk of individuals developing DVT whilst flying (Noddeland & Winkel, 1988; Quigley *et al.*, 2001; Lapostolle *et al.*, 2001; Mittermayr *et al.*, 2007). Often this is done through looking at lower limb oedema. Mittermayr *et al.* (2007) measured time-dependent changes in leg blood flow and lower limb volume before, during and after a simulated long-haul flight. The findings of the study were that the volume of the thigh was reduced by 31ml during sitting, compared to the lower leg which showed remarkable fluid accumulation of 145ml after 10 hours (Mittermayr *et al.*, 2007). Noddeland & Winkel (1988) conducted a study to 1) create

direct relationships between foot swelling, leg activity, skin temperature and perceived discomfort during 8 hours of sitting, and 2) study any marginal circulatory effects due to reduced barometric pressure which occurs in the cabin on intercontinental flights. The results obtained showed a 5.7% increase in the volume of the inactive foot during the 8 hour sitting period, compared to the active foot. It was also found that barometric pressure of 540mmHg (cabin pressure on intercontinental flights) had no effect on foot swelling compared to a barometric pressure of 750mmHg (ground level pressure). A large scale study conducted by Lapostolle *et al.* (2001) reviewed records of 56 passengers who were found to have pulmonary embolism after flying. It was found that the number of DVT cases increased with an increase in distance travelled. Among the 56 passengers with DVT, 75% had been travelling in economy class, 4% had travelled in business class and the class of travel was unknown for 21% (Lapostolle *et al.*, 2001). It was also found that 75% of passengers reported that they were completely immobile throughout the flight. The study continued to explain that the sitting position is strongly associated with venous stasis and increased blood viscosity, with a substantial decrease in blood flow, particularly in the legs occurring after one hour of sitting (Lapostolle *et al.*, 2001).

Stiffness

Prolonged sitting in a constrained or fixed posture has been associated with long term static loading of the body, which is considered a risk factor for the development of musculoskeletal complaints and discomfort (Luttman *et al.*, 2010; Cascioli *et al.*, 2011). The importance of movement and its relationship to stiffness and potential discomfort can be explained by discussing the thixotropic properties of muscle (Cascioli *et al.*, 2011). Thixotrophy was derived from the Greek *thixis* and *–trophy*, and means “transformation by touch” (Axelson, 2005). The term thixotropy was introduced by Buchthal & Kaiser (1951) in connection with skeletal muscle physiology (Axelson, 2005). It was found that muscle fibre stiffness was temporarily reduced by one single stretch movement and that the stiffness returned during a resting interval (Axelson, 2005). The thixotropic property of muscle is thought to result from an increase in the number of stable actin and myosin filaments when the muscle is at rest, thereby increasing muscle stiffness (Spernoga *et al.*, 2001; Cascioli *et al.*, 2011). A linear relationship has been found between the time a muscle

remains still and the stiffness of that muscle in response to a stretch (Spernoga *et al.*, 2001). Relaxed muscles stiffen considerably with an increase in the amount of time spent in a relaxed position (Lakie & Robson, 1988). After resting, the increased stiffness can be immediately reduced by active or passive movements, thought to be related to the stable bonds between actin and myosin molecules being broken or prevented from forming (Lakie & Robson, 1988; Spernoga *et al.*, 2001). Spernoga *et al.* (2001) showed this relationship. It was found that after a modified, hold-relax stretching protocol, hamstring flexibility was significantly increased. However, this flexibility only remained for 6 minutes, after which flexibility started to decrease and quickly returned to baseline stiffness (Spernoga *et al.*, 2001).

Literature suggests that there may be a relationship between stiffness and the amount of time spent sitting (Beach *et al.*, 2005; Cascioli *et al.*, 2011). Beach *et al.* (2005) found that lumbar spine stiffness was significantly reduced in males after 1 hour of prolonged sitting. Women on the other hand were found to have variable response in lumbar spine stiffness (Beach *et al.*, 2005). It was found that after 2 hours of sitting the participants, specifically the females, were unable to be pulled through the same range of lumbar flexion angles that were attained before sitting. These findings suggest that relatively short duration exposures may cause changes at the tissue level (Beach *et al.*, 2005).

It has been explained that passengers sitting in aircraft seats are exposed to restricted and cramped sitting conditions (Cascioli *et al.*, 2011). This may cause passengers to suffer from stiffness and cramps in their legs (Cascioli *et al.*, 2011). A study conducted by Quigley *et al.* (2001) interviewed passengers to find out their perceptions of comfort whilst flying. When asked to specify the causes of their discomfort, the passengers highlighted the lack of space to move in their seat. 70% of the passengers also highlighted the importance of a good seat design to allow for the adoption of different postures as well as to change postures easily (Quigley *et al.*, 2001). Along with aches and pains, and numbness, passengers also associated these sitting conditions with increases in stiffness (Quigley *et al.*, 2001).

Spinal load

It has been stated that when seated, biomechanical strain is placed on the human musculoskeletal system, increasing the load placed on the lumbar sacral region of

the spine (Todd *et al.*, 2007). This region is shown to be the weakest link in the kinematic chain (Pheasant & Haslegrave, 2006). Todd *et al.* (2007) explains how the load placed on the spine is caused by forces determined by body weight, tension in the surrounding muscles and ligaments, intra-abdominal pressure as well as any external load. When standing, the centre of gravity is positioned anterior to the spine, creating a flexion moment. Therefore, to maintain this posture, the flexion moment must be counteracted by an extensor moment which is generated by the back extensor muscles (Todd *et al.*, 2007). The lumbar spinal muscles have very small moment arms, and so it is necessary for them to generate large forces to counteract the forward-bending moment (Todd *et al.*, 2007). Therefore, the major force acting on the spine in usually from the activity of the spinal muscles (Todd *et al.*, 2007). When a person moves from standing to sitting, the contribution of the passive tissues has to be increased to support the trunk (Beach *et al.*, 2005). If individuals sit for prolonged periods of time, it could result in sustained pressure on the spine, contributing to fluid loss of the intervertebral discs, leading to decreased height of the spine and eventually lower back pain (Beach *et al.*, 2005).

Eklund & Colett (1984) have described the possibility of determining spinal loading through spinal shrinkage. However, other studies have reported an increase in spinal height after prolonged sitting (van Deursen *et al.*, 2001). Although the mechanisms of this are not completely understood, the increases found in spinal height have been attributed to time-varying postural adjustments (Kraemer *et al.*, 1985). Imposing movements have been said to reduce and even reverse the flow of fluid from the discs, reducing spinal shrinkage (Roberts *et al.*, 1998; van Deursen *et al.*, 2001). The increase in spinal height was also attributed to decreased magnitude of spinal loading in sitting relative to that undergone in previous activities (Kraemer *et al.*, 1985). These theories can be substantiated by a study conducted by van Dieen *et al.* (2001), who studied the effects of dynamic office chairs compared to stationary office chairs on spinal shrinkage. The results showed that spinal shrinkage was significantly reduced when participants sat in the dynamic office chair compared to a fixed chair (van Dieen *et al.*, 2001).

It has been suggested that the posture of the spine whilst sitting influences spinal loading (O'Sullivan *et al.*, 2002). O'Sullivan *et al.* (2002) reported that an upright sitting posture resulted in increased activity of the internal obliques, superficial

lumbar multifidus and the thoracic erector spinae muscles, suggesting a postural stabilising role for these muscles. Moving from an upright sitting posture to a slumped posture decreases the activity of these muscles, transferring the load from active stabilising structures to passive spinal structures (O'Sullivan *et al.*, 2002; Solomonow *et al.*, 2003). Wilke *et al.* (1999) found that sitting in an upright position, compared to a more slumped posture increased loading placed on the spine. The relaxed sitting posture was found to reduce muscle activity as well as intervertebral disc pressure.

Whilst numerous studies have investigated the role of office chairs and sitting postures on spinal pressure, there are no known studies that have looked at the effects of aircraft seats on spinal and intervertebral disc pressure. It would be interesting to see how different aircraft seats affect spinal loading and whether this correlates to passengers' perceptions of discomfort.

In-chair movement

Constrained postures, with little chance of movement, have been associated with prolonged contractions of the musculoskeletal system, causing muscular fatigue and complaints (Bendix *et al.*, 1986). In-chair movement is a measure that has been used to provide an objective measure of sitting discomfort in previous studies (Bhatnager *et al.*, 1985; Bendix *et al.*, 1985, Fenety *et al.*, 2000). The underlying assumption in these studies was that individuals' in-chair movements will be little at the start of sitting. As time passes, they will increase their in-chair movements, most likely due to increased feelings of discomfort (Fenety *et al.*, 2000). The reason for this is because sitting in a certain posture leads to the constant contraction of certain muscles, which could cause muscular fatigue and complaints (Bendix *et al.*, 1986). Therefore, changing sitting posture is associated with an individuals' attempt to increase their level of comfort (Tan *et al.*, 2009). While the relationship between in-chair movement and discomfort is difficult to understand as some movement is necessary to prevent undesirable static loading of the musculoskeletal system (Winkel, 1986), studies have clearly demonstrated a linear relationship between discomfort and seated movements. In a study conducted by Fenety *et al.* (2000), it was found that upright sitting posture was maintained for approximately 15 minutes. After 30 minutes there was a significant increase in the amount of in-chair

movement, which was taken as a sign of increased discomfort. At the end of 2 hours the in-chair movement had increased further (Fenety *et al.*, 2000).

In the past, research has focused on sitting postures and the effect of these postures during the performance of certain activities. A field study conducted by Grandjean *et al.* (1983) assessed the preferences of visual display terminal (VDT) operators. Bendix *et al.* (1986) evaluated in-chair movements in relation to seat height and backrest angle of a tiltable office chair. Fujimaki & Mitsuya (2002) studied the seated posture for VDT work, specifically focusing on the advantages of a 'slumped' posture. Research has also been conducted on people's postures whilst watching television (Von Rosmalen *et al.*, 2009), whilst Bronkhorst & Krause (2005) observed the posture and activities of 1 700 passengers in a commuter train when designing a new train seat. However, these studies focus on postures adopted during the performance of specific tasks and do not focus specifically on individual choice of posture adoption whilst seated.

Kamp *et al.* (2011) conducted a study to determine how people choose to sit in certain situations, specifically with regards to travelling by train. The passengers were observed by means of video recordings and photographs. From pilot studies, different postures were defined and classified in order to record them easily and quickly during the observation process (Kamp *et al.*, 2011). The classification of the postures can be seen in Table 2.

Table 2: Identified postural positions (Kamp *et al.,* 2011)

	Description
Head	Free of support
	Against headrest
	Supported by hands
Trunk	Free from backrest
	Against backrest
	Lounging (slumped back)
Arms	Free from armrests
	Upon armrests
	Only elbow
Legs	Both feet on floor
	Crossed
	Other

The observation of 568 individuals showed that there are three preferred postures that individuals will adopt when travelling by train. These can be seen in Figure 3. The most preferred posture of individuals (40%) was with the head free from support, trunk against the backrest, arms free from armrests and both feet on the floor. The second most popular position (15.1%) was head against the headrest, back in a slumped position, arms on the armrests and both feet on the floor. The third most preferred posture (12.5%) was head free of support, trunk against the backrest, arms free from armrests and legs crossed (Kamp *et al.*, 2011).

Figure 3: The three most observed postures adopted whilst travelling by train (Kamp et al., 2011)

While there is a fair amount of research of posture whilst sitting in automobiles, trains and busses, there is only one known study that observed the posture of passengers whilst sitting in an aircraft. The study was conducted by Tan *et al*. (2009) to observe the sitting postures of aircraft passengers travelling on a long-haul flight. While only 15 passengers were observed, it allowed for a better understanding of the types of postures that are typically adopted whilst flying. Based on the observations, 7 postures were identified. These can be seen in Figure 4. These sitting postures were then measured and evaluated in a separate study through both subjective and objective measures. From the results it was found that the sitting position with torso turned and the head facing the seat in front was considered the most comfortable. The participants also preferred to sit with their torso turned and their head to the side, resting their head on the headrest. The least favourable position was found to be sitting with the head tilted to the side and the hands resting between the neck and the head (Tan *et al*., 2009). While this study provides insight into the sitting postures whilst flying it must be remembered that this was during a long-haul flight of 12 hours. Sitting in an aircraft seat for up to 12 hours would increase the amount of discomfort experienced by the passengers, possibly resulting in increased change of posture. It would also provide the passengers more opportunity to sleep. The results might not be the same for a flight that was only 3 hours in length. The results however do allow for greater insight into different postures adopted whilst sitting.

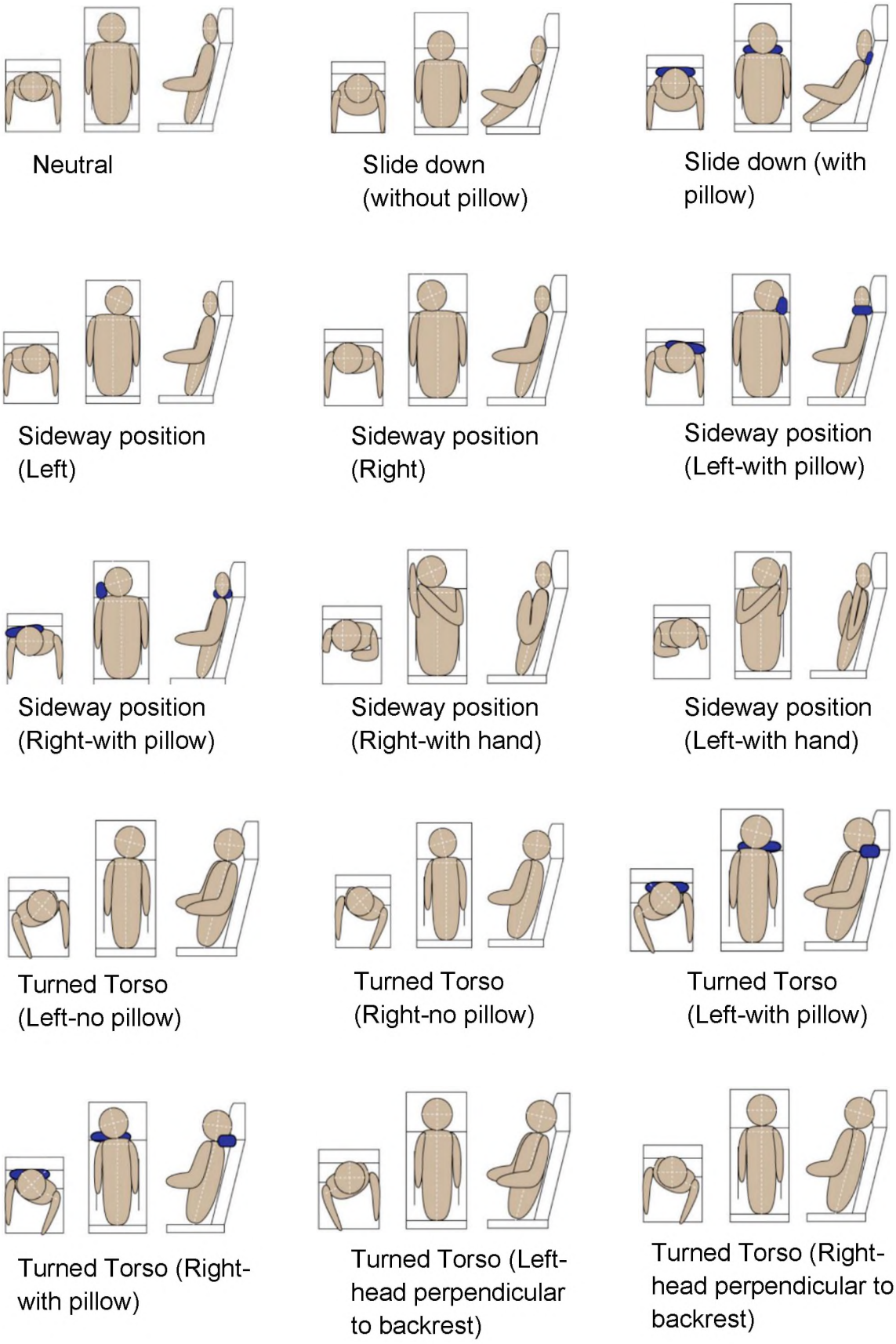

Figure 4: Sitting Postures Adopted Whilst Flying (Tan *et al.,* 2009)

THE AIRCRAFT SEAT

Research focused on passenger comfort whilst flying has identified aircraft seats as one of the key factors affecting passenger comfort (Richards & Jacobson, 1977; Vink *et al.*, 2012). Investigating aircraft seats is critical as this is where passengers spend the majority of their time during air travel. It plays an important role in fulfilling passenger comfort expectations (Tan *et al.*, 2009). The design of aircraft seats differs to that of office chairs or cars as the purposes of the chairs differ. The cost of the aircraft also requires the airline company to use space on the aircraft in the most economical manner in order to increase the number of passengers that can be transported at one time. This often results in a decrease in the size of the aircraft seat and compromises passenger comfort (Quigley *et al.*, 2001; Hinninghofen & Enck, 2006).

Countries who form a part of the Joint Aviation Authorities (JAA) do not currently have regulations regarding aircraft seat spacing, with the exception of the UK (Quigley *et al.*, 2001). The UK Civil Aviation Authority (CAA) Notice 64 regulates the minimum seat space dimensions for all UK registered aircraft over 5700kg, carrying 20 passengers or more (Quigley *et al.*, 2001). Brundrett e*t al.* (2001) explain how the CAA proposes a seat pitch that ranges from 76-86cm in economy class travel on scheduled airlines. The space allocated for seat width on economy class travel ranges from 38-49cm (Brundrett *et al.*, 2001). Quigley *et al.* (2001) conducted a study, due to the trend of generally increasing body dimensions within the European population. The study was based on the most up-to-date anthropometric data taken from PeopleSize and Adultdata. The anthropometric data was used to review how adequate the dimensions in the Airworthiness Notice 64 (AN64) are and to develop revised dimensions based on this (Quigley *et al.*, 2001). The dimensions of AN64 are based on the 5^{th} and 95^{th} percentile of passenger anthropometrics, meaning that at least 10% of passengers will not be accounted for (Quigley *et al.*, 2001). The findings of the study suggested that the current aircraft seat standards are inappropriate for the majority of the population. For example, it was found that the current width of typical economy class seats, particularly with regards to the distances between armrests, is inadequate to accommodate larger bodied passengers. 10% of European passengers would struggle with seat access/egress and posture change once seated, with even the widest armrest distance encountered in the study

(Quigley *et al.*, 2001). The inadequate seating standards conflict with the needs of the passenger as they are expected to sit in cramped and restricted seating conditions (Noddeland & Winkel, 1988; Nadadu & Parkinson, 2009). This observation, combined with prolonged immobility results in passenger discomfort and dissatisfaction.

Parameters of aircraft seats that affect comfort

There are several characteristics of aircraft seats that have been found to affect passenger comfort (Brundrett, 2001; Hinninghofen & Enck, 2006; Vink & Brauer, 2011; Vink *et al.*, 2012). These characteristics include aesthetics, seat width, backrest angle, seat pitch and seat height. It is important to remember however that these factors do not act in isolation, but are rather interlinked, together affecting passengers' perceptions of comfort and discomfort.

Seat pitch and legroom

Of all the characteristics of aircraft seats, studies have shown that the most important aspects affecting passenger comfort is the seat pitch and available legroom (Richards & Jacobson, 1977; Vink *et al.*, 2012). Seat pitch is defined as the distance from the point of a seat in one row, to the same point of a seat in the next row (Kremser *et al.*, 2012). The space allocated for seat pitch varies between airlines. The range for seat pitch in economy class on scheduled airlines ranges from 30-34in. (76-86cm). Business class allows for a much greater seat pitch, ranging from 38-60in. (97-152cm) (Brundrett, 2011). Nadadur & Parkinson (2009) explain how seat pitch is governed by two basic parameters: cabin length and the number of rows of seats in the cabin. Seat pitch, cabin length and the number of seat rows determines the number of passengers that an aircraft can accommodate. An increase in seat pitch can dramatically reduce the number of passengers which would lead to a loss in revenue. Due to this, airlines tend to decrease seat pitch so as to prevent this loss (Kremser *et al.*, 2012). Decreasing seat pitch is problematic as it comes at a cost to passenger comfort and satisfaction. A decreased seat pitch reduces the amount of legroom available for each passenger and can cause feelings of restriction (Kremser *et al.*, 2012).

Two studies were conducted by Vink *et al.* (2012) to determine ways in which to improve passenger comfort whilst flying. The first study analysed 10 032 trip reports,

while the other consisted of 153 interviews with passengers that had just landed at the Amsterdam airport. From the results, there were three positive comments that were most prevalent. The first was that a pitch of 33in. was considered comfortable, with anything less resulting in decreased comfort. The second comment was that the seat pocket for magazines, when placed at the level of the headrest, increased legroom and so was viewed in a positive light. 'Special' seats, such as exit row seats, no neighbours and upgrades were considered to be positive as they also increased space. The most negative aspect from the reports was that it was good that the flight was not longer, as the seat pitch caused severe discomfort in the legs, particularly with regards to the knees. Passengers also mentioned tight and cramped seating conditions as well as the problem of someone reclining in the seat in front of them as this hampers leg movement (Vink *et al.*, 2012).

The effect of seat pitch on passenger well-being was also studied by Kremser *et al.* (2012). In this study, an interior aircraft mock-up was built, with seat pitches ranging from 28in. to 43in. The results from the study showed that it was easier for the participants to adopt a comfortable sitting posture and to change their posture with a growing seat pitch (Kremser *et al.*, 2012). However, it was noted that from a seat pitch of 36in. and greater, saturation was reached, with no change in comfort levels being experienced (Kremser *et al.*, 2012). The results also found that passengers experienced decreased feelings of being restricted with an increased seat pitch, but at a pitch of 36in. and greater, participants complained of feeling 'lost' as the increased pitch allowed for too much space (Kremser *et al.*, 2012).

Seat pitch and legroom do not only affect comfort, but they also impact how much passengers are willing to pay for their tickets. Balcombe *et al.* (2009) conducted a survey to establish how legroom would impact the amount of money customers would be willing to pay. The results from the survey showed that passengers would pay an extra €22 for additional seat pitch. However, willingness to pay extra was shown to be affected by factors such as age, income and gender (Balcombe *et al.*, 2009). The results suggest that older passengers are more concerned with comfort than younger passengers and so would be more likely to pay extra for additional space. Higher earning individuals are also willing to pay up to €33 compared to lower earning individuals who would only pay up to €16 (Balcombe *et al.*, 2009). Females

are more willing to pay more for additional seat width, whereas males would prefer to pay for additional seat pitch (Balcombe *et al.*, 2009).

Seat pitch is not only important to consider from a comfort and profit perspective but needs to be analysed from a safety point of view as well. When an aircraft has to make an emergency landing, the passengers are required to adopt the 'brace position' (Chandler, 1993). The brace position is assumed by bending the upper body forward as far as possible. The chest must be close to the thighs and knees and the head must touch the seat in front. The hands must be placed on top of one another, on top of the head, with the forearms tucked in against the side of the face (Quigley *et al.*, 2001). This can be seen in Figure 5 below.

Figure 5: Recommended crash brace position (Quigley *et al.*, 2001).

Adopting the brace position is considered important during crash landings as it has been found to reduce the risk of head injuries (Brownsen *et al.*, 1998). The ability to adopt the brace position is said to be dependent on the amount of space between seat rows. Quigley *et al.* (2001) found that the current seating requirements did not provide enough space for passengers to adopt the brace position. It was found that to accommodate passengers up to the 95th percentile of World male sitting height, a

seat pitch of 41in. would be needed, compared to current seat pitches which are set significantly shorter than this (Quigley *et al.*, 2001).

The backrest

The role of a chairs' backrest is to lessen the stresses applied on the vertebral column by relaxing the erector spinae muscles, while maintaining lumbar lordosis (Corlett & Eklund, 1984). A chair that is appropriately designed will consist of a backrest that provides sufficient lumbar support, reducing the load placed on the spine (Corlett & Eklund, 1984). While a backrest is known to reduce spinal pressure, it has also been stated that the angle of the backrest is also of importance. It has been argued that the more reclined the backrest, the greater the reduction in lumbar muscle activity, thereby reducing the lumbar load (Kayis & Hoang, 1999). However, there is much controversy within the literature as to whether or not seats considered to be the most comfortable by the user are in fact biomechanically optimal (Todd *et al.*, 2007). During seated work, Corlett & Eklund (1984) showed a direct relationship between spinal shrinkage (used as a measure of biomechanical strain) and comfort ratings. However, van Dieen *et al.* (2001) found no relationship, while Carcone & Keir (2007) showed that comfort was rated highest in conditions that would not necessarily be considered biomechanically optimal. Oyama *et al.* (2003) compared sitting in an upright posture to sitting in a reclined posture for a 20 minute typing task. Sitting in a reclined posture decreased seat pan pressure but increased backrest pressure compared to when sitting in a more upright posture (Oyama *et al.*, 2003). Similar results were found by Kyung & Nussbaum (2013) who examined differences in car driver seats. It was found that peak pressure ratio at the upper back was higher when participants were in a more reclined position, indicating that a more upright sitting posture provided more support to the upper back (Kyung & Nussbaum, 2013).

It is therefore necessary to practice caution when designing seats as there is a complex interplay between comfort ratings and biomechanical strain (Todd *et al.*, 2007). What complicates this interplay further is the task that is being performed whilst seated. Vink & Brauer (2011) stated that the comfort of the backrest angle depends on the activity that is being performed by the individual whilst sitting. While watching television, Rosmalen *et al.* (2009) found that individuals preferred a backrest angle of 110 degrees. However, Nathan-Roberts *et al.* (2008) state that 100

degrees is preferable. Park *et al.* (2000) observed postures whilst driving and found that an average backrest angle of 117 degrees was preferred by participants.

While a considerable amount of research has been conducted on office chairs and car seats (Park *et al.*, 2000; Oyama *et al.*, 2003; Nathan-Roberts *et al.*, 2008), the importance of the backrest in aircraft seats seems to have been overlooked. Determining optimal backrest angle whilst driving is fairly straightforward as there is only one activity to be performed. However, there are a variety of activities that can be performed whilst flying (Hiemstra-van Mastrigt, 2015). In airplanes, passengers can eat, read, sleep and watch movies, resulting in constantly varied postures (Hiemstra-van Mastrigt, 2015). An aircraft seat backrest should be designed in such a way so as to provide desirable pressure distribution when the occupant is performing any one of these activities (Vink & Brauer, 2011). According to Aerospace Standard AS290B, the typical backrest angle on aircrafts ranges from 95-115 degrees (Aerospace standard, 1965; Goossens *et al.*, 2000). Vink & Brauer (2011) state that aircraft seats should have a backrest that tilts backwards and one that is adjustable, allowing passengers to change the backrest to their preferred angle.

The seat pan

While there are publications demonstrating the importance of various components of chairs and how they affect comfort, an early study by Renae *et al.* (1995) found the seat pan to be ranked as one of the top aspects needing improvement. The role of the seat pan in chair design is critical as it carries 65% of the user's body weight (Goonetilleke & Feizhou, 2001). Therefore, it is important to ensure that dimensions of the seat pan match those of the buttock-thigh area (Goonetilleke & Feizhou, 2001). According to Kroemer (2009), it is necessary for the seat pan to be cushioned and for the front edges to be rounded to decrease the pressure placed on the thighs. The addition of a backrest can further reduce pressure placed on the individual. It has been reported that tilting seat pans contribute to reducing spinal load (Kayis & Hoang, 1999), with studies recommending a seat pan that tilts 5 degrees forwards or between 5 degrees forwards or backwards (Parcells *et al.*, 1999; Smellie, 2003). However, a study conducted by Rasmussen *et al.* (2009) suggests that a seat pan angle that tilts forwards increases muscle activity to prevent the individual from slipping forward in their seat. A backward tilting seat pan angle is considered

beneficial as it is more likely to minimise spinal activity (Rasmussen *et al.*, 2009). The shear force model of Goossens & Snijders (1995) further explains this. Goossens & Snidjers (1995) state that whilst sitting, the weight of the body is distributed over the supporting surfaces. The distribution of weight depends on the mutual position of the surfaces. The shear force model, is a biomechanical model, showing how the inclination of backrest and seat pan influences the shear force on the seat. This model is restricted to the sagittal plane and static situations. The shear force model divides the seated human into four parts; shanks and feet, thighs, pelvis and upper body. They are connected by three links. The assumption is that the joints have no friction and that the four body parts are only able to produce push and pull forces. Additionally, it is limited to passive sitting, therefore, no muscle forces or ligament tensions are involved. The model uses equations to predict a relation between the inclinations of the backrest and seat pan in order to reduce the shear force applied on the seat.

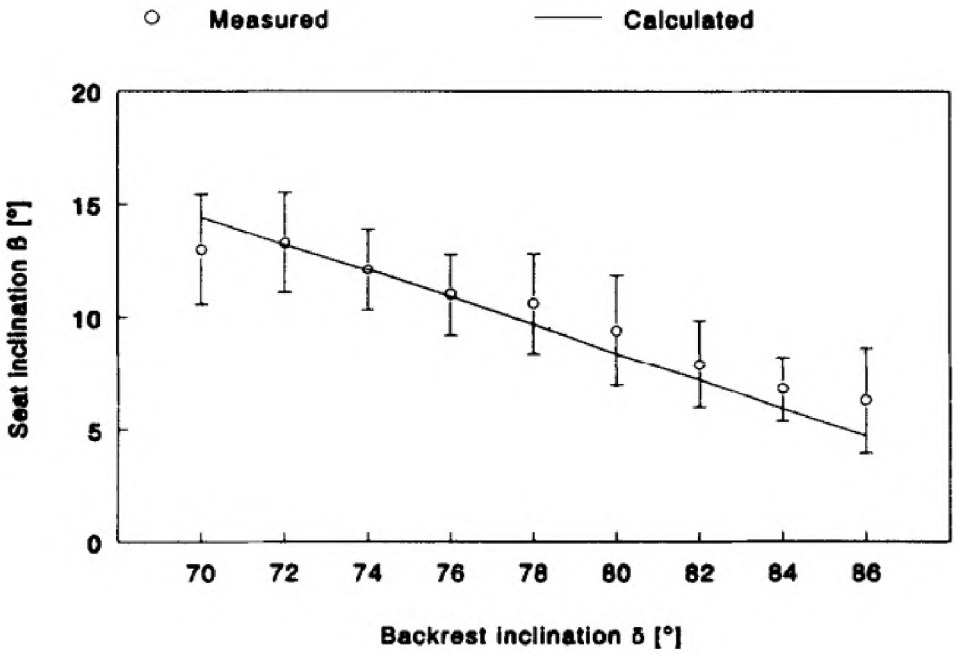

Figure 6: Seat and backrest inclinations that produce no shear force on the seat (Goossens & Snijders, 1995).

Figure 6 represents the seat and backrest inclinations that produce no shear force on the seat. The continuous line represents the combinations that are predicted by the biomechanical model. The mean and 95% confidence intervals for the measured

set inclinations on healthy participants are represented by the circles with error bars (Goossens & Snijders, 1995).

While it has been stated that the seat cushion is considered a primary component of the seat system (Adams *et al.*, 2002), there is no known research on how the seat pan may affect passenger comfort whilst flying, especially in combination with other seat characteristics such as the placement of the arm rests and the backrest angle.

Seat height

Research suggests that an appropriate seat height would be one that reduces the pressure placed on the underside of the thighs as a chair that is too high may increase the risk of developing ischemia and increasing discomfort (Mehta & Tewari, 2000). Ischemia is caused by a decrease in blood supply to the lower legs due to blockage of blood vessels leading to that area, causing pain and protective muscle contraction (Todd *et al.*, 2007). However, chairs should also not have a seat height that is too low as this may result in less weight being held by the individuals' feet, and being transferred to the ischial tuberosity instead (Quigley *et al.*, 2001). Ultimately, a seat should be designed in such a way so as to allow the individuals feet to remain in contact with the floor to allow the transfer of 25% of their body weight through the legs (Parcells *et al.*, 1999). This has been said to effectively reduce lumbar pressure (Parcells *et al.*, 1999). Furthermore, Zenk *et al* (2012) explain that in order to decrease the amount of discomfort experienced whilst sitting, it is important for the individuals' body weight to be distributed in the following manner: 50-65% of body weight should be in the buttocks, 10-30% on the thighs and 6% of body weight should be placed on the lower legs, on the front of the seat (Zenk *et al.*, 2012).

The seat height of all office chairs are designed with the 5^{th} and 95^{th} percentile of the population in mind (Openshaw *et al.*, 2006). However, different standards have been set for chair seat heights. Pheasant (1991) stated that seat height should be 380-535mm, the height of the popliteal. Popliteal height, as defined by The Business and Institutional Furniture Manufacturers Association (BIFMA), is the vertical distance from the surface of a footrest to the back of the knee (the juncture of the calf and thigh). Smellie (2003) increases this range to 590mm with 130mm leeway for adjustment. BIFMA (2002) recommends that users should be able to sit comfortably,

without any undue pressure on the underside of the thighs and that this is generally best achieved with a thigh-to-torso angle of no less than 90 degrees. While many seats are designed to be adjustable so that users can correct seat height accordingly, authors recommend using a foot rest with seats that are non-adjustable (Pheasant, 1991; Fujimaki & Mitsuya, 2002).

Seat height is a well-researched topic in the workplace and has slowly advanced to aircraft seat design. Optimising seat height on aircrafts is complex because both the passenger and the airline company have to be considered. A review by Schaedal, (1977) explains how passengers preferred the aircraft seat height to be the same as lower leg length. However, this review is outdated. A more comprehensive study conducted by Quigley *et al.* (2001) compared anthropometric data to aircraft seat recommendations. The results showed all minimum recommended seat heights to be between 30mm and 150mm higher than what the 1st percentile European female requires (Quigley *et al.*, 2001). This increases to between 60mm and 170mm for the world population. It was calculated that if a minimum seat height of 400mm was used, then 32% of British females would not be able to place their feet on the floor whilst seated (Quigley *et al.*, 2001). A seat height of 500mm would increase this percentage to 99.9%. However, a seat height that is too low may negatively affect taller passengers, forcing them to adopt uncomfortable leg and spinal postures and affecting their ease of seat egress (Quigley *et al.*, 2001). Hitos *et al.* (2007) showed how passengers' blood flow was affected by sitting in seats of different heights. Participants seated with their feet not touching the floor experienced a 2-fold reduction in blood volume flow compared to participants sitting with their feet flat, touching the floor (Hitos *et al.*, 2007). This reinforces the idea that seat height and subject leg length are significant factors that need to be considered when designing aircraft seats. Not only is seat height important with regards to preventing discomfort and health risks, it also affects how easily individuals are able to sit down and stand back up. The sit-to-stand movement is a frequently used function by individuals when moving from a sitting to a standing posture (Janssen *et al.*, 2002). It has been found that lowering the seat height increases the biomechanical demand of the sit-to-stand movement. In some cases this may even become impossible, depending on the individuals' age and health status (Janssen *et al.*, 2002).

Seat height also becomes problematic when looking at it from an economical perspective. A decreased seat height potentially increases the amount of legroom required by the passengers (Quigley *et al.*, 2001). This, in turn, demands an increase in seat pitch to accommodate the increased legroom requirements (Nadadur & Parkinson, 2009). An increased seat pitch reduces aircraft cabin capacity and may reduce the profit margin of the airline company as less passengers are able to travel at one time (Nadadur & Parkinson, 2009). However, an increase in passenger sitting comfort may allow for higher air fees. Therefore, the profit may be increased where the ratio of airfare to space needed is optimised.

Seat width

The width of the aircraft seat has been found to play a role in the amount of comfort experienced by passengers. The typical seat width in charter aircrafts and in economy class is 17 inches (Balcombe *et al.*, 2009), but can range between 15.5-20 inches (Brundrett, 2001). Although the recommended seat width is no less than 16in (Brundrett, 2001), previous research reports that approximately 25% of aircrafts used by airlines in the United Kingdom have seats narrower than this (Brundrett, 2001). Narrow seat widths are preferred by airline companies as it is a way in which to increase revenue. Balcombe *et al.* (2009) explain how increasing seat width could result in one seat having to be removed from each row, reducing the number of passengers that can be transported at a given time (Balcombe *et al.*, 2009). While a narrow seat width may increase revenue, it comes at a cost to passenger comfort. Comfort is impaired as narrow seat widths make for cramped seating, preventing the ability to adopt a comfortable posture as well as the possibility for posture change (Brundrett, 2001; Hinninghofen & Enck, 2006). The problem of narrow seat widths was demonstrated by Quigley *et al.* (2001), who found the seat width of four different types of airline seats to be inadequate and unable to accommodate larger passengers. For example: a passenger with a 95th percentile European female hip width (497mm), would find it difficult to fit into the widest seat width of the four chair designs that were studied (Quigley *et al.*, 2001). A woman with this hip width would in fact be 58mm wider than the space allows, leading to tissue compression at the level of the thighs and buttocks (Quigley *et al.*, 2001). Not only is this problematic for the individual, but it would affect the comfort of the passenger in the next seat. It may result in physical discomfort for all passengers in the same row, due to decreased

space. Additionally, this scenario would negatively affect the ease and speed with which passengers can egress the seat in the case of an emergency evacuation (Quigley *et al.*, 2001).

Other studies have also found passengers to report uncomfortable seating conditions whilst flying due to seat width (Blok *et al.*, 2007; Vink & Brauer, 2007; Vink *et al.*, 2012). Blok *et al.* (2007) conducted a study, whereby 152 individuals were interviewed just after their flight. The passengers were required to rate factors such as check-in, boarding, customs, luggage bins, the aircraft seat, in-flight entertainment, noise, climate, staff attention and hygiene (Blok *et al.*, 2007). The comfort experienced, from check-in to landing was rated on a scale of 1 to 5 (1 = very bad comfort, 2 = bad, 3 = average, 4 = good, 5 = very good comfort). Of all these factors, the aircraft seat received the lowest comfort ratings, with seat width receiving an average rating of 3 (Blok *et al.*, 2007). Vink *et al.* (2012) analysed 10 032 internet trip reports from May 1st 2008-October 1st 2008. The results showed that a number of the passengers reported a seat width that was too narrow, particularly due to the fact that the armrests were too wide. It was also found that the majority of complaints were situated around the lack of personal space, particularly for arms, shoulders and head and luggage stowed close to the passenger.

Aesthetics

An additional consideration with respect to aircraft seat design is the aesthetic value, as this is one of the first things passengers notice when they look at the seat (Hiemstra-van Mastrigt, 2015). Based on factors such as shape, size, texture and colour, passengers will already have begun to form an opinion of how comfortable the seat is going to be (Vink & Brauer, 2011). Comfort, however, is not only influenced by styling or appearance. Colour also has the potential to affect the mood, feelings and perceptions of an individual (Park & Han, 2003; Vink & Brauer, 2011). For example, white has been found to create a neutral effect, while red and orange creates a positive effect. Yellow is associated with creating a cheerful and warm effect, and blue with creating a subduing effect (Niku, 2009). This was shown by Vink *et al.* (2012), who asked passengers to rate the comfort of the seat they were sitting in. One of the most frequently mentioned comments referred to the covering of the seat, with passengers perceiving a seat covered in lightly coloured material to be more comfortable (Vink *et al.*, 2012). However, it is important to note that different

people and cultures assign different identities to various colours, which will affect their perceptions and experiences of comfort (Bellizzi *et al.*, 1983). Designing chairs with specific colours and patterns that relate to the populations' cultural values and identities then becomes important as this could increase subjective satisfaction and increase perceptions of comfort (Park & Han, 2003).

OTHER FACTORS AFFECTING SITTING COMFORT

While it is clear that the aircraft seat can have a major impact on passenger comfort, there are other aspects that also play a role. These include factors such as sitting duration, ease of seat access, psychological factors and individual characteristics (Quigley *et al.*, 2001; Cosmi *et al.*, 2008; Tan *et al.*, 2009). It is important to understand these as well to begin to develop a greater understanding of passenger comfort whilst flying.

Sitting duration

It has been well-established that sitting discomfort is strongly associated with time spent sitting (Helander & Zhang, 1997; Fernandez & Poonawala, 1998; Pheasant & Haslegrave, 2006; Cosmi *et al.*, 2008). However, it is not well-established how long it takes for individuals to give accurate comfort/discomfort ratings. Some researchers suggest that individuals need to sit in the chair for long periods of time, whilst others suggest that comfort can be determined fairly quickly. Fernandez & Poonawala (1998) stated that to obtain an accurate rating of comfort for a chair, it is necessary for individuals to remain seated for up to 3 hours. Lee & Ferraiuolo (1993) suggest that accurate comfort ratings can only be obtained if individuals remain seated for up to 8 hours. On the other hand, Pheasant & Haselgrave (2006) state that individuals only have to remain seated for a period of 5-30 minutes to provide an appropriate decision about a chair. Cosmi *et al.* (2008) support this through their findings of the comfort ratings of 6 office chairs that participants sat in for 20 minutes. Helander & Zhang (1997) stated that ranking chairs in order of comfort can be done in a matter of minutes. However, it is probable that physiological responses might not have set in yet, providing an incorrect rating of (dis)comfort (Pheasant & Haselgrave, 2006).

While there are a number of studies investigating the development of discomfort over time, the majority of these have been performed in work environments (Bazley *et al.*, 2015) or for car driver seats (Porter *et al.*, 2003). Sammonds *et al* (2017) studied the

effects of long-term sitting whilst driving on discomfort. The results showed that overall discomfort, seat fidgets and movements (SFM) increased over time. SFM were found to increase over time and are very closely related to overall discomfort ratings (Sammonds *et al.*, 2017). At no stage over the course of the trial, did discomfort ratings decrease. There is little research looking at the time-comfort relationship for aircraft seats. This relationship is interesting as there are a number of activities that can be performed by passengers whilst flying and it needs to be determined whether these have an effect on perceived discomfort (Hiemstra-van Mastrigt, 2015). Hiemstra-van Mastrigt (2015) explored the effect of sitting duration on passenger comfort whilst flying. The local perceived discomfort scales used consisted of a body map dividing the body into 22 regions. The participants rated their discomfort on a scale from 0 to 10 (0= no discomfort and 10=maximum discomfort). During the test four activities were simulated: sitting upright for take-off, eating/drinking, reading and sleeping/relaxing. The discomfort scores were analysed in two ways: the development of discomfort over time and the average increase in discomfort per activity. The results showed that discomfort did increase over time, however certain activities seemed to temporarily lower the feeling of discomfort. Participants reported feeling most refreshed after food had been served (34.8%), after sleeping (27%) and after walking through the plane (25.2%). However, this differed between long and short-haul flights. Short-haul passengers found the most refreshing activities to be food and sleep whereas long-haul passengers were most refreshed after walking through the plane (Hiemstra-van Mastrigt, 2015).

Activities performed whilst seated

Whilst chair design is important to consider to increase comfort and minimise risk of injury, such as lower back pain, it is also important to consider the type of activity that is performed whilst sitting. Dainoff *et al.* (2007) states that "a chair is not an isolated object, but needs to be considered as an integrated component in a complex work environment". This is important as often the same chair is used by different people, all performing different tasks. Reijneveld (2005) found that data entry workers make many more arm movements and trunk motions whilst sitting compared to CAM workers, while they often use the same chair. It is therefore not surprising that research has found that task demands play an important role on loads placed on the body and posture fixity, as well as on the level of discomfort experienced

(Groenesteijn, 2015). In their study, Vergara & Page (2000) found that different types of backrests used, are related to different comfort levels in reading and writing tasks. It was also found by Groenesteijn *et al.*, (2009), that during a reading task, a more reclined backrest angle was preferred compared to computer use, where a more upright backrest angle was preferred. It was also found that while travelling by train, passengers mentioned that to improve comfort whist reading, the inclination of seat and backrest could be improved (Groenesteijn *et al.*, 2015). With regards to sleeping, passengers suggested improved lumbar support and adjustability of headrest. Whilst sitting and talking, the passengers would have improved the seat inclination (Groenesteijn *et al.*, 2015).

Ease of seat access

While it is important to study the impact of sitting on passenger comfort, it is also necessary to take into consideration the ease of passenger access and egress to their assigned seat as this is considered a factor that affects passenger comfort. A study conducted by Quigley *et al.* (2001) reviewed passenger seat access and egress and found that adequate foot clearance was necessary when accessing/egressing the seat to avoid obstruction from seat structures. A recommended foot clearance of at least 350mm forward of the leading edge of the seat pan is needed, with an ideal clearance being 360mm (Quigley *et al.*, 2001). Quigley *et al.* (2001) also conducted a survey to determine the type of access problems passengers experience whilst flying. The results collected from the survey revealed that there was a lack of available space, both around the seat and in the isle. This is problematic as it prevented many passengers (32%) from vacating their seat as often as they would have liked (Quigley *et al.*, 2001). Other factors considered important by passengers were seats that were too narrow, the seat backrest in front of them and the armrests. A seat width that is too narrow, especially due to space taken-up by the armrests, could result in passengers having to lodge themselves into the seat, increasing difficulty when getting up (Quigley *et al.*, 2001).

It was also found by Quigley *et al.* (2001) that ease of seat access and egress is affected by age. It is said that older passengers find it more difficult to access seats in general, especially ones at a lower seat pitch. This is due to a lack of manoeuvrability as well as increased difficulty in supporting their own body weight when in an unbalanced position (Quigley *et al.*, 2001).

Not only is seat access/egress important from a passenger point of view, but also needs to be considered from a safety perspective. This is especially important in an emergency evacuation where passengers need to exit the plane as quickly and efficiently as possible (Tan *et al.*, 2009).

Psychological stress

It has been suggested that health problems may arise due to anxiety and unfamiliarity with airport departure procedures prior to flying, during flying and after flying (Tan *et al.*, 2009). Ahmadpour *et al.* (2014) states that during flying, the passengers' experience is affected by physical, social and situational inputs from the aircraft cabin. These include factors such as the aircraft seat, noise and temperature within the cabin. Psychological factors such as attitude towards flying are also said to play a role in passenger comfort (Ahmadpour *et al.*, 2014). Ahmadpour *et al.* (2014) found that psychological factors, such as 'peace of mind' were rated as the second most influencial factor in the discomfort reports. This means that although it is important to eliminate discomfort due to physical pain and health issues, it is just as important to eliminate factors affecting 'peace of mind'. These include safety issues and annoyance, such as loud noise, sudden movements and signs of wear and tear (Ahmadpour *et al.*, 2014). This is also important as flying is not a wholly natural activity for some individuals. Many passengers may find flying to be stressful, especially if they are not frequent flyers. This can result in physiological and psychological discomfort and stress (Tan *et al.*, 2009). Too much stress may cause individuals to become aggressive or over-react in certain situations which may endanger the individuals' health (WHO, 2007).

Studies have found that the aircraft seat is a contributing factor towards the stress and anxiety experienced by passengers, particularly those passengers seated in the middle seat (Tan *et al.*, 2009). The seat and seating arrangement may cause passengers to experience the feeling of 'being surrounded', leading to claustrophobia (Tan *et al.*, 2009). Kremser *et al.* (2012) looked at the influence of seat pitch on passengers' spatial perceptions. It was found that at a seat pitch of 28inch, individuals experienced increased feelings of restriction. From 28inch, feelings of restriction began to decrease, reaching saturation at a pitch of 40inch. It was also found that the feeling of being stressed due to a lack of available space reached its' minimum at 40inch (Kremser *et al.*, 2012). Seat pitches of up to 36inch

resulted in fairly constant feelings of "being lost", but this feeling intensified as seat pitch increased past this (Kremser *et al.*, 2012). Aircraft seats set to this pitch would easily double airfares due to the increased space need. Within the African context, this is important as only the rich would be able to afford travelling by aircraft if this recommendation were to be put into practise. However, it is also important to ensure that passengers' perceived restriction is minimised so as to enhance their flying experience. Whilst the aircraft seat is important in increasing passenger comfort, Ahmadpour *et al.* (2014) emphasise that aircrafts today need to enhance the perceptions of comfort and well-being by creating 'peace of mind' to provide security and relief. Feelings of security and relief are created, for example, when passengers are able to predict situations due to receiving enough information, care and attention (Ahmadpour *et al.*, 2014). Comfort is also enhanced due to 'proxemics - catering to passengers' privacy and autonomy. For example, one participant described how privacy (sufficient space to avoid physical contact with neighbours) resulted in a comfortable experience. 'Pleasure' needs to be created and is often done so by maintaining passenger satisfaction with the quality of the aircraft cabin environment (Ahmadpour *et al.*, 2014). All of these factors, if accounted for, will lead to an increase in passengers' perceived comfort due to decreases in psychological stress.

Individual characteristics

As has been previously discussed, the perception of (dis)comfort is a highly subjective phenomenon (de Looze *et al.*, 2003). Therefore, seat comfort is a subjective issue as it is the passenger who makes the final determination (Tan *et al.*, 2009). This means that perceptions of (dis)comfort will most likely be affected by individual characteristics such as age, gender and body mass index (BMI).

Age

It has been projected that with an increase in the number of individuals travelling by air, the populations' medium age will increase as well (McMullin *et al.*, 2014). This produces a challenge to airline companies as the older traveller may experience decreases in strength, agility, reaction times, hearing acuity, visual acuity, spatial orientation, mobility and bone and muscle composition (Hertzberg, 1972; McMullin *et al.*, 2014). These physiological and biomechanical changes all make travelling more difficult (McMullin *et al.*, 2014). It is therefore also possible that people of varying ages would experience differences in sitting comfort whilst flying. While studies

investigating aircraft seats and passenger comfort use participants of varying ages (Tan *et al.*, 2009; Kremser *et al.*, 2012; Hiemstra-van Mastrigt, 2015), none of these studies seem to compare the comfort ratings between individuals of different age groups.

Sex

The role of sex in seat design should be important to consider as the body proportions of males and females vary significantly (Hiemstra-van Mastrigt, 2015). Due to this it is likely that the comfort experienced whilst sitting will differ between males and females.

Moes (2007) found that sex was the best predictor of average sitting pressure. It was found that the average pressure was lower for females compared to males as females have a larger contact area due to a larger hip breadth. Another study demonstrated how preferences in sitting posture is affected by sex. Park *et al.* (2013) demonstrated in a driving simulation experiment that most female drivers preferred a slouched or upright sitting posture, compared to males who preferred a slouched or reclined posture. Dunk & Callaghan. (2005) also demonstrated the preferred different seating postures for males and females. The results showed that the average lumbar and trunk angles were significantly more flexed for males than females. The study also showed that when seated, the pelvis was posteriorly rotated for males, compared to females who anteriorly rotated the pelvis. From the results it was interpreted that males and females may be exposed to different loading patterns whilst seated and so may experience different pain generating pathways (Dunk & Callaghan, 2005). Therefore, it seems likely that different comfort responses would be given by males and females when sitting in an aircraft seat.

Hiemstra-van Mastrigt. (2015) explains how the average stature of a Dutch male between 20 and 30 years of age is 1848mm, which is 161mm taller than the average Dutch female. This means that an aircraft seat designed for the 5^{th} to 95^{th} percentile male, 1716mm, corresponds with a 66.7^{th} percentile female (Hiemstra-van Mastrigt, 2015). This is further complicated by the differences in body proportions between males and females. For example, the average sitting hip breadth is close to the average shoulder breadth for Dutch females (402mm vs. 422mm), in comparison to the 82mm difference in Dutch males (388mm vs. 470mm).

Tan *et al.* (2010) developed a questionnaire to determine where passengers experienced the most discomfort during sitting in an aircraft seat. The results showed that there were differences in body part discomfort between males and females. It was found that the female participants experienced a greater amount of discomfort over the course of the flight than males (Tan *et al.*, 2010). The results also showed that females reported greater discomfort in their upper body compared to males who experienced a greater amount of discomfort in their lower body (Tan *et al.*, 2010).

Body mass index

The anthropometric variance between individuals varies significantly and needs to be accounted for during chair design. One of the easiest methods of evaluating an individuals' anthropometry is by determining their body mass index (BMI). BMI is determined using the individual's stature and weight and can be calculated using the formula: BMI = mass (kg) / stature (m) ^{2} (Mei *et al.*, 2002). Determining BMI is important in chair design as studies have shown stature and mass to be a contributing factor to sitting (dis)comfort (Brundrett, 2001; Vink & Brauer, 2011). This is particularly problematic in the 21st Century as there seems to be a constant increase in the prevalence of obesity (Komlos & Baur, 2004). This means that the proposed minimum aircraft seat standards, based on data for the 5th and 95th percentile of passenger anthropometrics, now cater for less than the 77th percentile of the general population (Quigley *et al.*, 2001). Passengers who are taller and who weigh more than the average person require special attention as they are more likely to experience increased discomfort due to cramped and restricted seating conditions (Nadadu & Parkinson, 2009; Vink & Brauer, 2011). Tan *et al.* (2010) found that passengers with a higher BMI experienced greater lower body discomfort compared to passengers with a lower BMI. It has also been shown by Kremser *et al.* (2012) that passengers sitting posture is affected by their anthropometry which makes aircraft chair design complicated as different sitting postures are known to affect an individual's levels of (dis)comfort (Kremser *et al.*, 2012).

MEASURES OF SITTING COMFORT

Discomfort, as stated by de Looze *et al.* (2003) is a predominantly subjective phenomenon, and so the discomfort experienced will differ between individuals (Tan *et al.*, 2009). It is for this reason that subjective measures are predominantly used to determine individuals' perceived discomfort. Understanding individuals' discomfort is

typically done through questionnaires (Openshaw, 2011). Whilst it is often difficult for individuals to remain objective and unbiased when answering discomfort questionnaires, the researcher is able to gain a better understanding of what the participant is feeling and experiencing. Without the subjectivity, the human element can be lost (Openshaw, 2011). There are a number of subjective questionnaires that have been developed for this purpose. These consist of the Category Partitioning Scale (CP-50 scale), Local Perceived Discomfort (LPD), Shackel's General Comfort Rating (GCR) Scale, Corlett's Body Part Discomfort (BPD) questionnaire, Helander and Zhang's descriptors and the Body Area Chart Checklist (BACC).

The CP-50 scale is a method of measuring sitting discomfort, and more specifically, pain intensity (Mergl *et al.*, 2005; Franz *et al.*, 2014). The scale is arranged vertically, with a starting point of 0-no discomfort and is then continues with 5 discomfort categories: very slight, slight, medium, severe, very severe discomfort (Shen & Parsons, 1997). Each of these categories is further divided into 10 scale points to rate points above 50 for any extreme intensity (Lin *et al.*, 2009). Participants are first required to select the category that fits their perception, and then refine their judgement by choosing a number from 1 to 10 within the selected category (Lin *et al.*, 2009).

The Local Perceived Discomfort method has been used by Van der Grinten & Smitt (1992) and Groenesteijn (2015) to determine participants' perceived discomfort. This method consists of a map with 23 regions. Feelings of pain, numbness, pressure and tiredness underlie the feelings of discomfort (Groensteijn, 2015). A 6-point scale is used to assess discomfort, ranging from 0-no discomfort, through to 5-extreme discomfort (Kuijt-Evers *et al.*, 2007).

The Body Part Discomfort (BPD) Scale is an internationally recognised and practiced method of measuring discomfort (Corlett & Bishop, 1976) and has been used extensively for chair and seat evaluation (Shen & Parsons, 1997). The BPD scale portrays the body divided into 12 areas. Users indicate the areas where they experience the most discomfort and rate the intensity of their discomfort on a scale of 0 to 5, with 0 being the complete absence of discomfort and 5 being unbearable discomfort (Shen & Parsons, 1997).

Shackel's General Comfort Rating Scale is a one-dimensional, 11-point scale used for the assessment of chair comfort. This is a verbal scale, ranging from "I feel unbearable pain" through to "I feel completely relaxed" (Shackel *et al.*, 1969). Verbal rating scales are considered effective as it is often considered ineffective to ask users to rate their (dis)comfort without giving them some cues. Rating scale cues are considered beneficial as they not only remind the individual as to what is being rated but they also give provide anchors or guides to quantitative judgements (Christiansen, 1997). Shackel *et al.* (1969) instructed participants to use this scale to rate the comfort and discomfort of 10 different chairs.

In the 1990's, when people started questioning the linearity of comfort/discomfort, Helander & Zhang (1997) began using two sets of descriptors to determine individuals' perceptions of comfort and discomfort. The two sets of descriptors consisted of one set for comfort and another set for discomfort. The descriptors for comfort were related to relaxation, well-being and design aesthetics, including: I feel relaxed/refreshed/restful, the chair feels spacious and the chair looks nice. The descriptors for discomfort related to biomechanical factors, soreness and pain, including: I have sore muscles/heavy legs; I feel stiff/tired/pain/numb (Helander & Zhang, 1997). These were rated on a scale ranging from 1 to 9, with 1 being "not at all" and 9 being "extremely" (Helander & Zhang, 1997). It was thought that these descriptors would help individuals to differentiate between comfort and discomfort, allowing a more accurate account of perceptions whilst sitting (Openshaw, 2011).

The Body Area Chart Checklist (BACC) was used in a study by Lusted *et al.* (1994) to evaluate the seating of Qantas flight deck crew. This questionnaire required the participants to indicate which part of their body was experiencing discomfort and to then rate their discomfort on a 10cm unmarked, visual analogue scale (Lusted *et al.*, 1994). The scale starts with no pain/discomfort and ends with severe pain/discomfort. The participants then indicated what type of sensation was contributing to their discomfort. These included feelings such as aching, burning or tingling (Lusted *et al.*, 1994; Mehta & Tewari, 2000).

Tan *et al.* (2010) investigated the relationship between body part discomfort and travel time for economy class aircraft passengers. The results from the study show that after one hour of flying, there was a significant increase in discomfort

experienced by passengers. The results showed that passengers rated the shoulder as experiencing the most discomfort, followed by the neck and the right lower leg (Tan *et al.*, 2010). After five hours of travel it was found that the buttocks area was rated as experiencing the greatest discomfort, followed by the shoulder and the neck. It was also found that there was a significant difference between gender and discomfort after one and five hours of travel (Tan *et al.*, 2010). Males scored higher on body discomfort level at lower body sections than females, whereas females reported greater discomfort at upper body sections compared to males. Age also showed a significant difference in discomfort. Older passengers reported a greater discomfort, specifically with regards to the arm, compared to younger passengers (Tan *et al.*, 2010). It was also found that passengers with a higher BMI experienced greater lower body discomfort compared to passengers with a lower BMI.

From the research that has been conducted, it is clear that seat design is complex as all the above mentioned factors interact. However, this makes aircraft seat design important to study in order to gain an understanding of these interaction effects.

CHAPTER III
METHODOLOGY

INTRODUCTION

This study focused on the relationship between aircraft seat pan angle, seat height and backrest angle on passenger comfort as well as the use of cabin space as these are closely linked and are two concerns for airline companies. This is particularly important as Denel Aviation is considering the use of a non-adjustable backrest angle for the seats that will be used in SARA. Therefore, this study has two aims: 1) to determine how seat pan angle, seat height and backrest angle interact, affecting passenger comfort, ease of seat access, perceived restriction and space used for legroom and 2) to determine how seat pan angle and seat height, with the preferred backrest angle affects passenger comfort.

Independent variables

Seat height

One of the ways in which to better utilise cabin space could be through the manipulation of aircraft seat height. It was therefore considered necessary to understand the role that this factor plays. This study tested three different seat heights, a low, medium and a high seat height. A high and low seat height was chosen in order to establish whether a difference in comfort would be experienced between these two extremes. To determine whether the relationship was linear or not, a medium seat height was also chosen. To ensure that the effect of seat height would not interfere with the participants' stature, seat height was set relative to the participants' lower leg length, rather than having three absolute seat heights. Seat height was determined by ensuring that the high seat height allowed the participants knees to bend at a 90-degree angle, making sure that no unnecessary pressure was placed on the underside of the thighs. Increased pressure on the thighs could increase the risk of developing ischemia and increases the pressure placed on the lumbar spine (Mehta & Tewari, 2000). As a result, the high seat height was set by measuring the participants' popliteal height. Popliteal height, as defined by BIFMA (2002), is the vertical distance from the surface of a foot rest to the back of the right knee (the juncture of the calf and thigh). From literature, it was found that participants find it difficult to perceive differences in seat heights which are smaller

than 2cm (Helander, 2010). Pilot studies, conducted at the Human Kinetics and Ergonomics Department, also found that participants were unable to perceive differences in seat heights varying by 3cm and less. It was for these reasons that the medium seat height was set to 4cm lower than lower leg length and the low seat height was set to 4cm lower than the medium seat height.

Backrest angle

Backrest angle is known to affect both the comfort of the passengers as well as the space requirements in the aircraft cabin (Vink & Brauer, 2011). It was important to test backrest angle as Denel is considering the use of non-adjustable backrests. Determining which backrest angle was preferred by the participants would be beneficial to SARA as this would increase the comfort experience of their passengers. The typical aircraft seat consists of a backrest angle that ranges between 95 and 115 degrees (Goossens *et al.*, 2000; American Ergonomics Corporation, 2006). Testing backrest angles outside these ranges was considered necessary as it may affect passenger comfort as well as the use of cabin space. Therefore, for this study, seven backrest angles were tested, consisting of 90, 95, 100, 105, 110, 115 and 120 degrees. It was considered important to include 90 and 120 degrees to test these two extremes. A minimum of 90 degrees was decided upon as it would have been impractical to test an angle less than this. An angle less than 90 degrees would not save space and would require the participant to lean forward in the seat, resulting in significant discomfort. A backrest angle of 120 degrees was the maximum backrest angle tested as this angle goes beyond the maximum backrest angle (115 degrees) found in aircrafts. It was also considered unnecessary to test any backrest angle greater than this as SARA is a short-haul flight. Therefore, it is not necessary for passengers to be able to recline their backrest to a greater angle, as would be the case in a long-haul flight. Testing backrest angles of greater than 120 degrees would have also increased the number of seating conditions in this study, which would have resulted in a greater number of participants having to be recruited.

Seat pan angle

Incorporating seat pan angle into this study was deemed necessary as it was thought that the angle of the seat pan, combined with seat height, would affect which backrest angle the participants considered to be the most comfortable. Furthermore, it was thought that this may affect the amount of space used for legroom by the participants.

Due to the 5 degree increments in the backrest angles, it was considered appropriate to use seat pan angles varying by 5 degrees as well. Bendix & Biering-Sorenson, (1983) suggest that a 5-degree upwards seat pan angle may stabilize individuals whilst seated as it prevents them from slipping forward. However this also increases hip angle, resulting in the need for a more reclined backrest angle. This would increase the space needs of the aircraft cabin. The use of a 0-degree seat pan angle could save space as the hip angle is increased, possibly allowing for a more upright backrest angle. Smallman & Miller (2013) suggest that the seat pan should be angled in such a way so as to prevent the user from sliding forward in their seat. This is particularly important in aircraft seat design. While a 0 degree forwards seat pan angle may save space, as a more upright backrest angle could be employed, this would not necessarily be beneficial to the passenger. A 0 degree forwards seat pan angle may be impractical as it could result in passengers slipping out of their seat, particularly when decelerating. It was also important when testing seat pan angle, that the participants were able to differentiate between the seat pan angles. Helander (2010) conducted studies on office chairs and found that individuals cannot perceive differences in seat pan angles that differ by 3 degrees or less. As a result, a decision was made to test two seat pan angles. These consisted of a 0 degree and a 5 degree upwards seat pan angle.

Dependent variables

Perceived sitting comfort

Sitting comfort is a subjective phenomenon and varies from person to person (de Looze *et al.*, 2003). As a result, it is important to try to understand how seating factors play a role in sitting comfort and how this differs between individuals. Sitting comfort is also necessary to measure as the majority of complaints made by passengers whilst flying is the significant discomfort experienced due to the aircraft

seat (Richards & Jacobson, 1977; Vink *et al.*, 2012). While objective measures, such as measuring lower limb oedema, have been associated with sitting discomfort, these do not indicate how a person is feeling subjectively. The only method in which to subjectively gauge how (un)comfortable an individual is, is by measuring their perceived sitting comfort.

For this study, two different subjective methods of measuring sitting comfort were employed; an absolute rating of comfort and a comparative rating of comfort. As previously discussed, the first part of this study was to determine how seat pan angle, seat height and backrest angle affected the participants perceived comfort, ease of seat access, perceived restriction and legroom, as well as how seat pan angle and seat height affected the preferred angle of the backrest. Due to the high number of conditions, a comparative rating of comfort was used to determine this. This comfort rating allowed the participants to compare their current sitting condition to the comfort of the previous sitting condition, allowing for an easier way in which to measure comfort. Due to this method of measuring comfort, it would not have been possible to have two separate rating scales. The second part of this study was to determine the sitting comfort of seating conditions, consisting of the most preferred backrest angle for each seat pan angle and seat height. This was achieved using an absolute rating of sitting comfort.

Absolute rating of comfort

While there are other methods of rating comfort, such as The Body Part Discomfort Scale, these were considered inappropriate to use as they are more beneficial for measuring how comfort changes over a prolonged period of time. One of the easiest ways of measuring short-term sitting comfort is through the use of a subjective rating scale ranging from 0-10. This rating scale has been used in a number of previous studies and is deemed an effective measure of sitting comfort (Vink & Brauer, 2011; Vink *et al.*, 2012; Hiemstra-van Mastrigt, 2015). It was for this reason that the absolute rating of sitting comfort used in this study consisted of a scale ranging from 0-10, with 0 referring to maximum discomfort and 10 referring to maximum comfort.

Comparative rating of comfort

During pilot studies, it was found that while rating the comfort of many different seating conditions, the participants became confused, which resulted in low reliability

of comfort ratings. It was for this reason that a comparative rating scale was developed, so as to get a more precise measure of comfort between different parameters. As a result, the participants were able to compare their current sitting condition to their previous sitting condition. This was done using a scale ranging from -2 to +2, with -2 being significantly less comfortable than the previous seating condition, -1 slightly less comfortable, 0 no difference in comfort, +1 slightly more comfortable and +2 significantly more comfortable than the previous seating condition. While this is not a common method of measuring sitting comfort, it was considered the most appropriate way in which to do so.

Ease of seat access

Ease of seat access is an important factor to consider for several reasons. Firstly, ease of seat access has an economic criterion, whereby decreases in boarding time result in decreased costs. Secondly, it was thought that a seat that is easier to access may increase passengers overall sense of comfort. To measure ease of seat access, Quigley *et al*. (2001) used a subjective rating scale ranging from 1-5, with 1 being very difficult to access seat and 5 being very easy to access seat. This is the only known study that measures participant ease of seat access, and so was the reason for the use of this subjective rating scale ranging from 1-5 in this study.

Due to the economic effects of boarding time, as well as easy seat egress in the case of emergency situations, it was also considered important to measure how long it took the participants to sit down. The amount of time taken for the participants to sit down was recorded for every seating condition.

Legroom

Research conducted by Vink *et al*. (2012) and Kremser *et al*. (2012) state that the amount of legroom available on aircrafts is a constant cause of complaint. Therefore, this test included the measurement of legroom to gain an understanding of how the space needs of the participants differed with each seating condition. To measure legroom, the participants were asked to sit naturally, in a position they found to be the most comfortable. Therefore, this measure of legroom was not necessarily a measure of the maximum amount of space used, but merely provided an indication of where participants naturally placed their feet and whether this differed for different seating conditions. This measure of legroom did not indicate levels of discomfort as

no restriction was placed on the participants' legroom. In order to indicate discomfort, the space available for legroom would have to have been restricted, which would have resulted in more seating conditions to be tested. This would not have been possible in this study.

Perceived restriction

Previous research has highlighted that feelings of restriction are associated with passenger discomfort (Quigley *et al.*, 2001; Kremser *et al.*, 2012). However, this parameter evaluates beyond sitting comfort, providing insight into how sitting in different seating conditions makes individuals feel, particularly with regards to their perceived feelings of personal space. It was for this reason that it was considered important to determine how restricted the participants felt at chest height by the chair in front of them. This test only investigated the effect of seat height, seat pan angle and backrest angle on participants' perceived restriction and not different seat pitches, as it would have then been necessary to adjust the distance between the rows of seats. This would have increased the number of conditions to be tested and so was not possible. In a study conducted by Kremser *et al.* (2012), the participants were asked to rate how accurately certain phrases such as "I feel restricted" and "I feel restricted by the distances of the seating rows", applied to their present scenario. This was done using a five point scale ranging from 1 (strongly disagree) to 5 (strongly agree). This method was adapted in the present study by asking the participants to rate how restricted they felt at chest height by the chair in front of them, on a five point scale, with 1 being severely restricted, 3 neutral and 5 not at all restricted.

EXPERIMENTAL DESIGN

This study focuses on the interaction effects of seat pan angle, seat height and backrest angle on several dependent variables. In order to study this, four aircraft seats were placed in two rows. The minimum seat pitch found on economy class airlines as well as low cost carriers is 76cm (Brundrett, 2001, Hinninghofen & Enck, 2006). As this is the minimum seat pitch found, any seat pitch greater than this would likely result in increased comfort, faster access times and decreased restriction. It was for this reason that in this study, the distance between the two rows of aircraft seats were set to the minimum seat pitch of 76cm. The seat pitch was determined by

measuring the distance from the point of the seat in one row to the same point of the seat in the row in front. This was done by measuring from the backrest of the back seat to the same point of the backrest of the front seat with a measuring tape. Tape was then placed on the floor by the chair platforms to ensure that the distance between the two rows remained the same throughout the testing process.

While it was possible to control for seat pitch, seat pan angle, seat height and backrest angle, it was not possible to control for other factors such as seat width and seat pan length. It is known that these factors play a role in passenger comfort, however, including them would have increased the number of seating conditions and so was not possible. Therefore, the effects of these on the dependent variables on this study are unknown.

Due to the combination of the two seat pan angles, three seat heights and seven backrest angles, 42 seating conditions were created. This resulted in a short-term study consisting of a repeated measures design. While the use of a non-repeated measures design was considered and would have been feasible, it would have meant a significantly greater number of participants would have to have been recruited to provide reliable data. A repeated measures design was considered more appropriate for this study, even though it does come with its disadvantages. The biggest disadvantage being the order effect; the change in results over time due to factors such as boredom, fatigue and the learning effect. However, this was dealt with by randomising the conditions. A repeated measures design allowed for the recruitment of fewer participants, which made the testing process significantly more time efficient. It also meant that all the participants were able to sit in all the seating conditions, providing a better understanding of the effects of these on the dependent variables.

Table 3: The combination of the seating conditions and the order of testing.

Group 1	Seat Height	High	→	High	→	Medium	→	Medium	→	Low	→	Low
	Backrest Angle (degrees)	90→120		90→120		90→120		90→120		90→120		90→120
	Seat Pan Angle (degrees)	0		5		0		5		0		5
Group 2	Seat Height	High	→	High	→	Medium	→	Medium	→	Low	→	Low
	Backrest Angle (degrees)	120→90		120→90		120→90		120→90		120→90		120→90
	Seat Pan Angle (degrees)	0		5		0		5		0		5
Group 3	Seat Height	Medium	→	Medium	→	Low	→	Low	→	High	→	High
	Backrest Angle (degrees)	90→120		90→120		90→120		90→120		90→120		90→120
	Seat Pan Angle (degrees)	0		5		0		5		0		5
Group 4	Seat Height	Medium	→	Medium	→	Low	→	Low	→	High	→	High
	Backrest Angle (degrees)	120→90		120→90		120→90		120→90		120→90		120→90
	Seat Pan Angle (degrees)	0		5		0		5		0		5
Group 5	Seat Height	Low	→	Low	→	High	→	High	→	Medium	→	Medium
	Backrest Angle (degrees)	90→120		90→120		90→120		90→120		90→120		90→120
	Seat Pan Angle (degrees)	0		5		0		5		0		5
Group 6	Seat Height	Low	→	Low	→	High	→	High	→	Medium	→	Medium
	Backrest Angle (degrees)	120→90		120→90		120→90		120→90		120→90		120→90
	Seat Pan Angle (degrees)	0		5		0		5		0		5

Table 3 displays the way in which the seating conditions were permutated, as well as the order of testing. Each participant began the testing process with either a high, a medium or a low seat height. The backrest angle was set to either a 90 degree or a 120 degree angle for each participant. The first seat height and the first seven backrest angles were tested with one seat pan angle. The same seat height and the seven backrest angles were then tested with the second seat pan angle. Once the seven backrest angles were tested with the first seat height and both seat pan angles, the height of the aircraft seat was adjusted to the second seat height. Once again, the seven backrest angles were tested with both seat pan angles at the second seat height. This process was repeated until all backrest angles had been tested with all seat pan angles and seat heights.

During the rating of the 42 seating conditions, the comparative rating of comfort was used. The way in which the comparative rating of comfort was measured can be seen in Table 4 below.

Table 4: An example case for the comparative comfort rating, measured over the seven backrest angles.

Perceived Comfort (-2, -1, 0, +1, +2)								
Seat Height	Seat Pan Angle (degrees)	Backrest Angle (degrees)						
		90	95	100	105	110	115	120
Low	0	x	x+2	x+2+2	x+2+2+2	x+2+2+2+2	x+2+2+2+2+1	x+2+2+2+2+1+0
Low	5	x	x+2	x+2+1	x+2+1+0	x+2+1+0+0	x+2+1+0+0-1	x+2+1+0+0-1-1
Medium	5	x	x+2	x+2+1	x+2+1+0	x+2+1+0+0	x+2+1+0+0-1	x+2+1+0+0-1-1
Medium	0	x	x+2	x+2+2	x+2+2+2	x+2+2+2+0	x+2+2+2+0-1	x+2+2+2+0-1-1
High	0	x	x+2	x+2+2	x+2+2+2	x+2+2+2+1	x+2+2+2+1-2	x+2+2+2+1-2-1
High	5	x	x+2	x+2+1	x+2+1+1	x+2+1+1+1	x+2+1+1+1-2	x+2+1+1+1-2-1

Table 4 shows an example of the comparative rating of comfort for the 42 seating conditions. Once all 42 seating conditions had been rated, the most preferred backrest angle for each seat pan angle and seat height was calculated. To do this, the reference points (x) were added up and the backrest angle with the greatest number was taken as the most preferred backrest angle. For example, in Table 4, it can be seen that backrest angles of 115 and 120 degrees resulted in the greatest reference points (x+9). In the case that the participants rated two backrest angles as having no difference in comfort (as can be seen in the first row of Table 4, with a 115 and a 120 degree backrest angle), then the more upright backrest angle; in this case, 115 degrees, was taken as the most preferred backrest angle. This was done as the more upright backrest angle was considered more likely to save space in the aircraft cabin.

This same process was applied to participants who started testing with a 120 degree backrest angle. Once the participants had completed all 42 seating conditions, the preferred backrest angle for each seat height and seat pan angle was determined. This resulted in 6 seating conditions, which can be seen in Table 5 below.

Table 5: An example of the experimental set-up for the absolute comfort ratings of the six seating conditions.

Seat Height	Seat Pan Angle (degrees)	Backrest Angle (degrees)	Comfort Rating (0-10)
Low	0	115	8
Low	5	105	3
Medium	0	105	6
Medium	5	110	6
High	0	100	3
High	5	110	9

In order to rate the comfort of the six seating conditions, the aircraft seat was set to one seat height and one seat pan angle. The backrest was adjusted to the angle that was rated as the most comfortable by the participants in the previous stage of testing. The participants rated their sitting comfort of all six seating conditions on the absolute rating scale ranging from 0 to 10. Once the absolute comfort ratings were known, it was possible to convert the comparative comfort ratings into absolute comfort rating values, for the purpose of statistical analyses. This was done in Excel in the following manner. Refer to appendix C for further details.

1) To convert from relative comfort to absolute comfort, it first needed to be established how much the absolute comfort needed to be adjusted by for each backrest angle. The difference was named 'dif-ref'. This was done by stating that if the 'absolute' backrest angle is equal to the 'relative' backrest angle, then the dif-ref in absolute comfort between the backrest angles is 0.

However, if the 'absolute' backrest angle is not equal to the 'relative' backrest angle, then dif-ref is absolute comfort minus relative comfort.

2) To calculate the 'difference', the dif-ref of each seat height or seat pan angle for all seven backrest angles was added up.

3) From here it was possible to convert the relative comfort to absolute comfort. To attain the new absolute comfort rating, the 'difference' was added to the relative comfort.

PARTICIPANT CHARACTERISTICS

For this test, in order to attain sufficient statistical power, a total of 80 participants were recruited. It has been suggested in the literature that sitting is experienced differently by males and females due to differences in body proportions (Hiemstra-van Mastrigt, 2015). Other factors such as sitting posture and body part discomfort have also been stated to be affected by sex (Tan *et al.*, 2010; Park *et al.*, 2013). As a result, sex was considered a covariate for this study and the 80 participants were split equally into 40 males and 40 females. Due to the variety of different individuals that are likely to be transported by SARA, the participants were not limited by race, ethnicity or culture.

Individuals who travel by aircraft consist of a wide range of different ages, yet there seems to be very little research investigating the relationship between age and sitting comfort whilst flying. Low & Chan (2002) suggested that comfort, as well as health risks, may be affected by age. In their study, Tan *et al.* (2009) included participants of all ages, yet the results do not compare the comfort ratings of the older and younger participants. It was for this reason that age was considered as a covariate. For the simplicity of this study, the males and females were split equally into two age groups only. Research states that factors such as bone density, muscle mass and strength peak at about 30 years of age, after which they begin to decline (Adams & Roughley, 2006; Taylor & Johnson, 2008; Ryall *et al.*, 2008). It was for this reason that the participants were split equally into 18-30 year olds and 31-60 year olds.

The body composition of individuals is an important consideration with regards to chair design. Nadadu & Parkinson (2009) and Vink & Brauer (2011) state that

passengers who are taller or who weigh more than the average individual are likely to experience increased sitting discomfort due to increases in cramped and restricted seating conditions. As a result, stature, mass and BMI were considered as covariates during this study. There are a number of methods that can be used to measure an individuals' body composition, such as hydrostatic weighing and bioelectrical impedance. However, BMI was chosen as it is a simple, cost-effective and widely used method of determining an individuals' body composition. During the testing procedure, the participants' lower leg length was measured to determine seat height.

No exclusion criteria was applied in the recruitment process as the participants were not exposed to long-term sitting in one seating condition, but were continuously accessing and egressing the aircraft seat. This was not considered risky as the majority of participants were most likely accustomed to sitting for prolonged periods of time. The constant access and egress of the aircraft seat also minimised the risk of the participants being exposed to musculoskeletal discomfort and other factors such as deep vein thrombosis.

INSTRUMENTATION

During this study, the aircraft seat had to be altered so as to be able to change the seating conditions. The participants' stature, mass and lower leg length were measured and recorded. The manner in which this was done is discussed below.

Seat height

This study tested three different seat height, a low, medium and a high seat height. In order to change the height of the aircraft seat, the height of the floor was adjusted rather than the height of the aircraft seat itself. To change the height of the floor, the aircraft seats were mounted onto a platform. The section of the platform, between the legs of the aircraft seats, was cut out. Planks of wood were cut to the correct size and used as an adjustable floor. To adjust the height of the floor, a pulley system

Figure 7: The pulley system devised to adjust the height of the aircraft chairs by altering the height of the floor.

was devised, consisting of four chains attached to each corner of the platform. This allowed for the platforms to be lifted and lowered to change the seat height. This system can be seen in Figure 7 below.

Backrest angle

This study tested seven backrest angles, ranging from 90 to 120 degrees. It must be noted however that the backrest angle was set relative to the seat pan angle. Therefore, the backrest angle for a 5 degree seat pan angle was more reclined than the same backrest angle with a 0 degree seat pan angle. The way in which the backrest angles were measured and calculated can be seen in Figure 8 below.

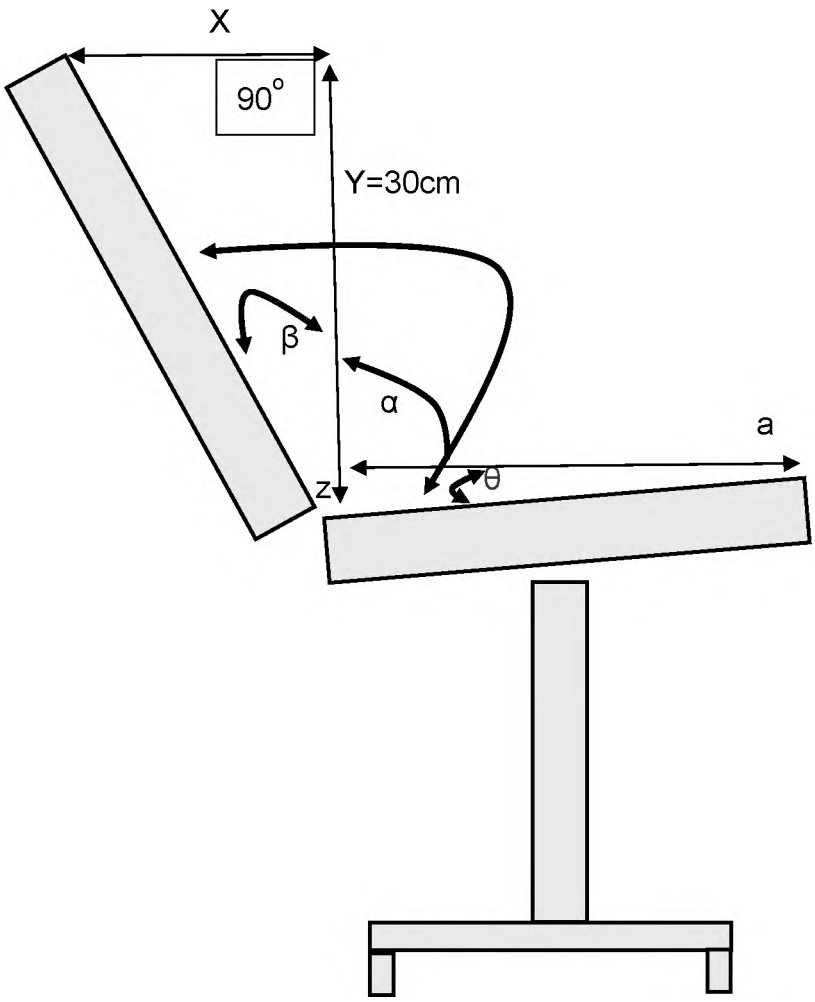

Figure 8: The method used to measure the different backrest angles.

Key: X = distance between the backrest and the vertical line (Y)

Y = the distance of the vertical line

Z = the distance between the seat pan and horizontal line 'a'

a = the length of the seat pan

β = the angle between the backrest and the vertical line (Y)

α = the backrest angle when measured from the vertical line to the seat pan

θ = the angle of the seat pan

Calculation 1: To determine β

$$\text{Tan}(\beta) = X / 30\text{cm}$$

$$\beta = \text{Tan}^{-1}(X/30)$$

Calculation 2: To determine the angle of the seat pan

$$\text{Tan}(\theta) = z / a$$

$$\theta = \text{Tan}^{-1} (z/a)$$

Calculation 3: To determine the angle of α

$$\alpha = 90^{o} - \theta$$

Calculation 4: To determine the angle of the backrest

$$\text{Backrest angle} = \beta + \alpha$$

Seat pan angle

Two seat pan angles were included in this study, a 0 degree seat pan angle and a 5 degree seat pan angle. To determine the original angle of the seat pan, the formula above was used: $\text{Tan}(\theta) = z / a$. To adjust the seat pan to the correct angle, two planks of wood were levelled to the correct thickness and length and were placed underneath the back of the seat pan of the aircraft seats.

Time taken to sit down

During this study, the participants' ease of seat access was measured by timing, with a stopwatch, how long it took them to sit down in their seat. To measure this accurately, a marker was placed on the floor next to the 'aisle' seat. The participants were required to access their seat from this same point for every seating condition. This ensured that the participants walked the same distance for every condition, confirming that accessing times were due to the different seating conditions and not the distance moved. It was also ensured that the backrests of the seats in both rows were set to the same angle. With respect to boarding time, the seat setting would not normally be relevant as the backrests are set in an upright position for take-off. However, if a fixed backrest angle were to be used, ease of seat access due to seat settings would be relevant, as is the case in this study.

Legroom

The posture of the participants' feet, whilst sitting, was measured to gain an understanding of how seating conditions affected the space needs of the participants. While this was not a measure of maximum space used for legroom in each seating condition, the aim was to determine whether or not the seating conditions affected the participants' leg posture, and how much space this required. In the course of this study, leg posture will be referred to as 'legroom'. Legroom was measured by securing a measuring tape to the adjustable platform. The start of the measuring tape was set in line with the edge of the seat pan and was secured along the edge of the platform. This allowed for the amount of space used for legroom by the participants to be measured quickly and efficiently. Legroom was measured from the edge of the seat pan to the furthest point of the participants' shoe.

BMI

In order to calculate the participants' BMI, the stature and mass of the participants needed to be measured. Stature was measured by using the Holtain Limited Stadiometer. The participants were required to take-off their shoes and stand with their back against the stand of the stadiometer. The participants were instructed to look straight while the headboard was lowered onto their head and their stature recorded. This procedure was taken from those performed in other studies (Dieen *et al.*, 2001; Cascioli *et al.*, 2011). To measure the participants' mass, the Toledo Trek Scale was used. The participants were asked to stand barefoot on the platform of the scale until their weight had been recorded.

Lower leg length

It was necessary to measure the participants' lower leg length to be able to calculate the three heights of the aircraft seat. Lower leg length was measured by determining popliteal height. To measure lower leg length, the participants were asked to stand in an upright posture, with their legs straight. The distance from the floor to popliteal height was measured with a measuring tape. Although lower leg length is normally measured without shoes, for this study, it was necessary to measure the participants' lower leg length with shoes. It is typical for aircraft passengers to board the aircraft and sit down with shoes. If they do happen to remove their shoes during the flight, this is normally done once seated, during the course of the flight. The participants

were advised to wear shoes that they would find comfortable to get in and out of a number of seating conditions.

EXPERIMENTAL PROCEDURE

An ethics application for this study was submitted to the Human Kinetics and Ergonomics Department Ethics Committee for review. The ethics application outlined the risks and benefits associated with the study, informed consent, privacy, anonymity and confidentiality. Once the application was approved, the participants were recruited. The participants were required to attend one laboratory session at the Human Kinetics and Ergonomics Department. Prior to testing, the participants were given a letter of information (Appendix A1) and were briefed on what the study was about and what they were required to do. If the participants were comfortable with partaking in the study, they were asked to sign a letter of informed consent (Appendix A2). The participants were made aware that they could pull out of the study at any time.

Upon arrival for testing, the procedure was explained to the participants and they were made aware of all the measures that would be taken during testing, consisting of the comfort ratings, ease of seat access, perceived restriction and legroom. The stature and mass of the participants was measured and recorded and from this BMI was determined. The participants' lower leg length was measured. The participants were then provided with the opportunity to practise getting in and out of the seat they would be sitting in so that they could become accustomed to stepping up onto the platform. This ensured that the time taken to sit down was not influenced due to familiarisation. Before starting the testing procedure, it was ensured that the distance between the two rows of aircraft seats was set to a seat pitch of 76cm.

The first part of the study consisted of the participants rating the 42 seating conditions. The first seating condition consisted of the aircraft seat being set to one seat height, one seat pan angle and either a 90 or a 120 degree backrest angle. The backrest of the aircraft seat in front was adjusted to the same angle. When indicated, the participants were required to move from the marker placed on the floor to the aircraft seat in which they were required to sit down on. The time taken to do so was timed with a stop watch. The participants were instructed to sit in a natural position that they felt comfortable in. Once seated, the participants were asked to rate how

restricted they felt at chest height by the backrest of the chair in front of them. The amount of space they used for legroom was measured and recorded. The participants were then asked to remain seated for a minimum of 30 seconds to determine how (un)comfortable they felt. For this first seating condition, the participants did not give a comfort rating. After the participants had determined their sitting comfort, they were asked to vacate the seat. The backrest angle of both seats was then adjusted to either a 95 or a 115 degree backrest angle. The seat height and seat pan angle remained the same. Once again, the participants were asked to stand by the marker on the floor, after which the time taken for them to access their seat was recorded. Once seated the participants rated how easily they thought they were able to access their seat. They then rated their perceived restriction at chest height and the amount of space used for legroom was recorded. The participants were asked to remain seated for a minimum of 30 seconds while they determined how (un)comfortable they felt in their current seating position compared to the previous seating position. The participants rated their sitting comfort on the comparative rating scale ranging from -2 to +2. This procedure continued until the comfort of each backrest angle had been compared to the comfort of the previous backrest angle with the first seat height and seat pan angle. After the rating of the seven backrest angles, the aircraft seat was set to the second seat pan angle. The seat height remained the same. Once again, the same procedure as above took place until all seven backrest angles had been rated with the same seat height and the new seat pan angle. The seat was then adjusted to the second seat height. The participants partook in the same procedure as above. This continued until all 42 seating conditions were complete.

After the participants had rated the 42 seating conditions, it was possible for the most preferred backrest angle for each seat pan angle and seat height to be determined. This resulted in 6 seating conditions. The participants were required to rate the absolute comfort of each seating condition. This was done on a scale ranging from 0 to 10. The aircraft seat was set to one seat height, one seat pan angle and the preferred backrest angle for that specific seat height and seat pan angle. The participants were asked to sit down in the seat for a minimum of 30 seconds, after which they gave a comfort rating. The participants were asked to stand up while the aircraft seat was adjusted to the next seat pan angle and backrest

angle most preferred for that particular seat height and seat pan angle. Once again, the participants sat in the seat for a minimum of 30 seconds, after which an absolute comfort rating was given. This procedure took place until all 6 seating conditions received a comfort rating.

STATISTICAL HYPOTHESIS

Various seat pan angles, seat heights and backrest angles (independent variables) were tested in combinations with one another to determine their effects on participants' ease of seat access, perceived subjective comfort, perceived restriction and space used for legroom (dependent variables). It was thought that an optimised seat height may save space on the aircraft. However, this would also likely affect passenger comfort. As a result, the following statistical hypotheses were developed:

1) The null hypothesis (H_O) states that backrest angle (90-120 degrees) will not affect the participants' perceived comfort, ease of seat access, perceived restriction and legroom at any of the two seat pan angles three seat heights tested. The alternate hypothesis (H_A) states that the backrest angle (90-120 degrees) will affect the participants' perceived comfort, ease of seat access, perceived restriction and legroom at any of the two seat pan angles and three seat heights tested.

   Where:
   μ = dependent variables (perceived subjective comfort, ease of seat access, perceived restriction and legroom)
   Bra = backrest angle

   H_O: $\mu(Bra90) = \mu(Bra95) = \mu(Bra100) = \mu(Bra105) = \mu(Bra110) = \mu(Bra115) = \mu(Bra120)$

   H_A: $\mu(Bra90) \neq \mu(Bra95) \neq \mu(Bra100) \neq \mu(Bra105) \neq \mu(Bra110) \neq \mu(Bra115) \neq \mu(Bra120)$

2) The null hypothesis (H_O) states that seat pan angle and seat height, at the preferred backrest angle, will not have an effect on the participants' perceived

subjective comfort. The alternate hypothesis (H_A) states that seat pan angle and seat height, at the preferred backrest angle, will have an effect on the participants' perceived subjective comfort.

Where:
μ = Perceived subjective comfort
0spa = 0 degree seat pan angle
5spa = 5 degree seat pan angle
Lsh = Low seat height
Msh = Medium seat height
Hsh = High seat height
PrefBra = Preferred backrest angle

H_O: μ(0spa)(Lsh)(PrefBra) = μ(0spa)(Msh)(PrefBra) = μ(0spa)(Hsh)(PrefBra) = μ(5spa)(Lsh)(PrefBra) = μ(5spa)(Msh)(PrefBra) = μ(5spa)(Hsh)(PrefBra)

H_A: μ(0spa)(Lsh)(PrefBra) ≠ μ(0spa)(Msh)(PrefBra) ≠ μ(0spa)(Hsh)(PrefBra) ≠ μ(5spa)(Lsh)(PrefBra) ≠ μ(5spa)(Msh)(PrefBra) ≠ μ(5spa)(Hsh)(PrefBra)

CHAPTER IV
RESULTS

This was a short-term investigation studying seat comfort with respect to seat pan angle, seat height and backrest angle. These seating characteristics consisted of a 0 and 5 degree seat pan angle, a low, medium and high seat height, as well as seven backrest angles ranging from 90 to 120 degrees. The dependent variables investigated consisted of perceived subjective comfort, ease of seat access, perceived restriction and legroom. Perceived comfort consisted of two rating scales. The first was a comparative rating scale ranging from -2 to +2, with -2 being significantly less comfortable than the previous seating condition and +2 being significantly more comfortable than the previous seating condition. This comfort scale was used during the rating of the 42 seating conditions. The second comfort scale was an absolute rating of comfort consisting of a scale ranging from 0 to 10, with 0 being maximum discomfort and 10 being maximum comfort. This comfort scale was used during the rating of the last 6 seating conditions. Once these values were obtained, the comparative comfort ratings were transferred to absolute ratings for the purpose of data analysis. Ease of seat access consisted of two measures, time taken to sit down and an ease of seat access rating scale. Perceived restriction was measured at chest height to determine how the backrest angle of the chair in front of the participants affected how much space they perceived to have. Legroom was measured to determine how the three seating factors affected space needs. Legroom was determined by asking the participants to sit naturally, in a position they felt most comfortable.

This study used a repeated measures design. All 80 participants recruited were required to sit in all seating conditions for a minimum of 30 seconds. The data collected was analysed in Statistica using an analysis of variance (ANOVA).

OVERVIEW OF RESULTS STRUCTURE

The data collected from this study will be dealt with by first giving an overview of the participant characteristics. This will be followed by the effects of seat pan angle, seat height and backrest angle on the dependent variables. The effects of the covariates (age, sex, stature, body mass, BMI and lower leg length) on the dependent variables will then be reported on.

DEMOGRAPHICS

The demographics of the participants who partook in this study were recorded and can be seen in Table 6 below.

Table 6: Mean demographic values of the participants. (± refers to the standard deviation).

	18-30 years		31-60 years	
(n=20)	40		40	
Sex	Males: 20	Females :20	Males: 20	Females :20
Age (years)	24±2	23±2	41±9	40±7
Stature (cm)	176.1±7.2	163±7.4	177.4±7.1	166.1±5.1
Body Mass (kg)	80.3±10.7	64.1±10	90±16.5	70±10
BMI (Kg/m^2)	25.9±3.4	24.1±3.7	28.5±4.7	25.5±3.9
Lower Leg Length (cm)	53±3.1	49.1±2.2	53.8±2.7	51.4±2.7

THE EFFECTS OF SEAT PAN ANGLE, SEAT HEIGHT AND BACKREST ANGLE ON THE DEPENDENT VARIABLES

The following results will report on how seat pan angle, seat height and backrest angle affect participants comfort ratings, legroom, perceived restriction, ease of seat access and their preferred backrest angle for each seat pan angle and seat height.

The effects of seating conditions on comfort ratings

The results from this study were analysed to determine whether seat pan angle, seat height and backrest angle affected the comfort ratings given by the participants for the 42 seating conditions.

Table 7: Statistical significance (error probability) for comfort, affected by seat pan angle, seat height and backrest angle. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	$p<0.001$
Seat Height	$p<0.001$
Backrest Angle	$p<0.001$
Seat Pan Angle x Seat Height	$p=0.306$
Seat Pan Angle x Backrest Angle	$p<0.001$
Seat Height x Backrest Angle	$p<0.001$
Seat Pan Angle x Seat Height x Backrest Angle	$p=0.138$

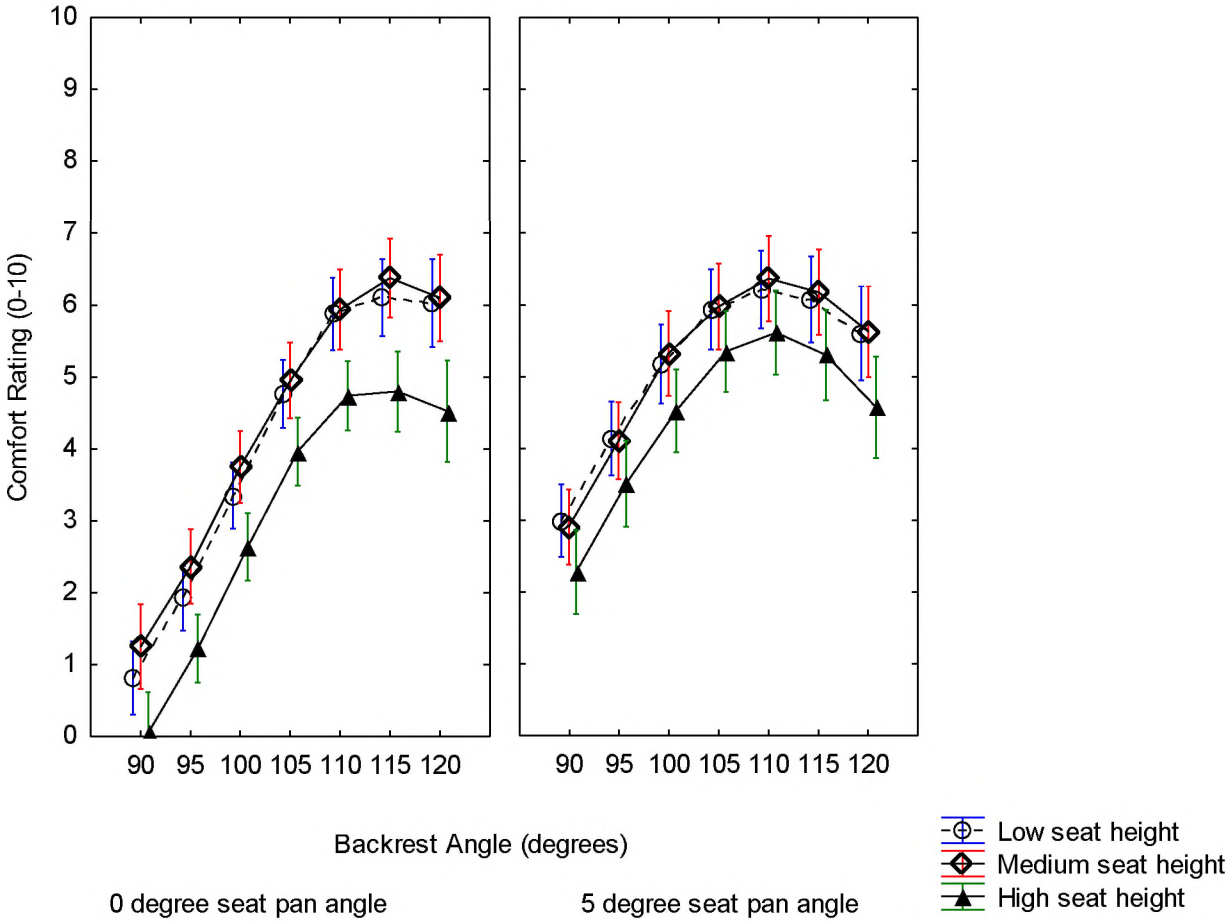

Figure 9: The effect of seat pan angle, seat height and backrest angle on comfort ratings. Error bars denote 95% confidence interval.

Seat pan angle, seat height and backrest angle significantly affected the participants' comfort ratings (Table 7). For all seat heights and seat pan angles, comfort ratings increased significantly as the backrest angle increased from 90 to about 110 degrees. From 110 degrees onwards, comfort ratings decreased. With regards to seat height, a low and medium seat height produced significantly greater comfort ratings compared to a high seat height. At a 5 degree seat pan angle, comfort ratings were significantly greater compared to comfort ratings at a 0 degree seat pan angle, particularly with a high seat height (Figure 9). It must be noted that backrest angle was measured relative to the seat pan angle. Therefore, there was a 5 degree difference in backrest angle between the two seat pan conditions.

The effects of seating conditions on legroom

Table 8: Statistical significance (error probability) for legroom, affected by seat pan angle, seat height and backrest angle. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	p<0.001
Seat Height	p<0.001
Backrest Angle	p=0.003
Seat Pan Angle x Seat Height	p<0.001
Seat Pan Angle x Backrest Angle	p=0.508
Seat Height x Backrest Angle	p=0.127
Seat Pan Angle x Seat Height x Backrest Angle	p=0.171

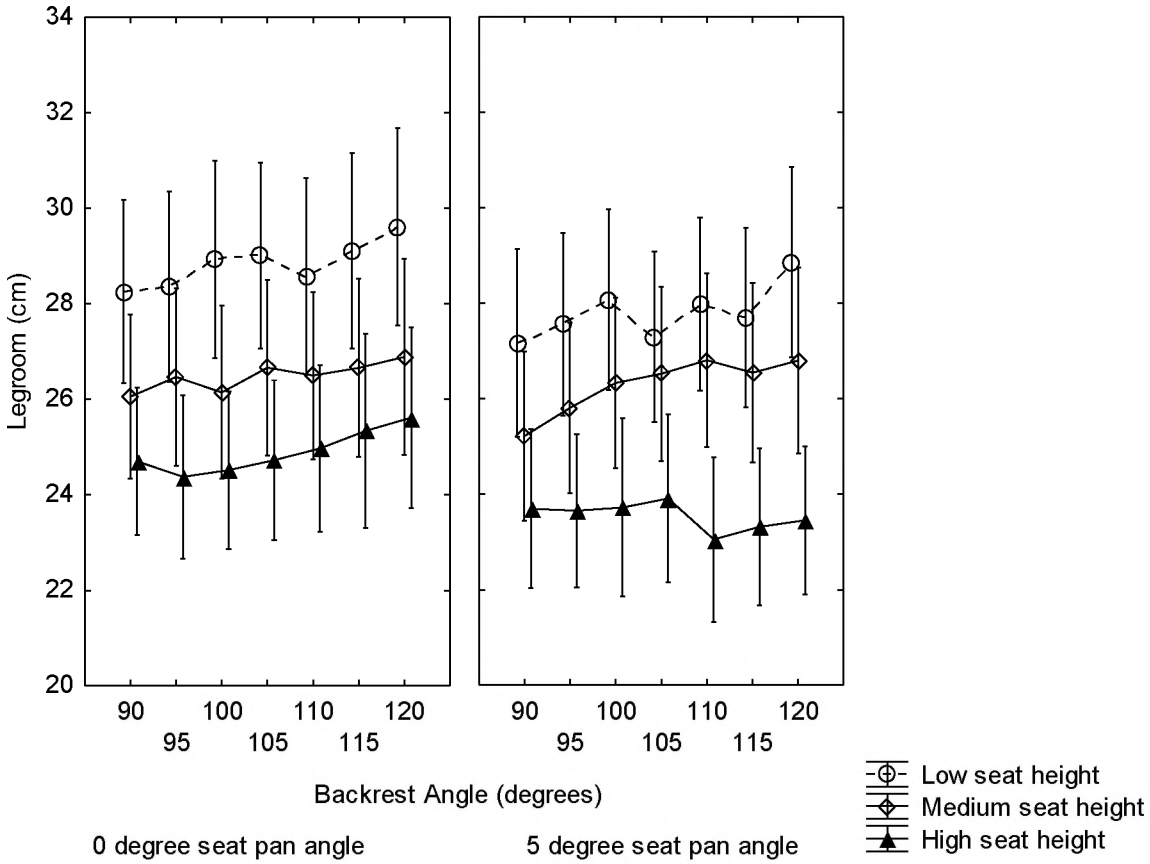

Figure 10: The effect of seat pan angle, seat height and backrest angle on legroom. Error bars denote 95% confidence interval.

Seat pan angle, seat height and backrest angle significantly affected the amount of space the participants use for legroom (Table 8). With regards to seat height, the space used for legroom was significantly less with a high seat height compared to a low and medium seat height. A low seat height also resulted in significantly greater legroom compared to a medium seat height. With regards to seat pan angle, significantly less legroom was used with a 5 degree seat pan angle compared to a 0 degree seat pan angle. While the trend is not a linear one, the space used for legroom increased as the backrest angle moved from 90 to 120 degrees. The space used for legroom was greatest at 120 degrees (Figure 10).

The effects of seating conditions on perceived restriction

Table 9: Statistical significance (error probability) for perceived restriction, affected by seat pan angle, seat height and backrest angle. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	$p<0.001$
Seat Height	$p=0.213$
Backrest Angle	$p<0.001$
Seat Pan Angle x Seat Height	$p=0.434$
Seat Pan Angle x Backrest Angle	$p<0.001$
Seat Height x Backrest Angle	$p=0.029$
Seat Pan Angle x Seat Height x Backrest Angle	$p=0.003$

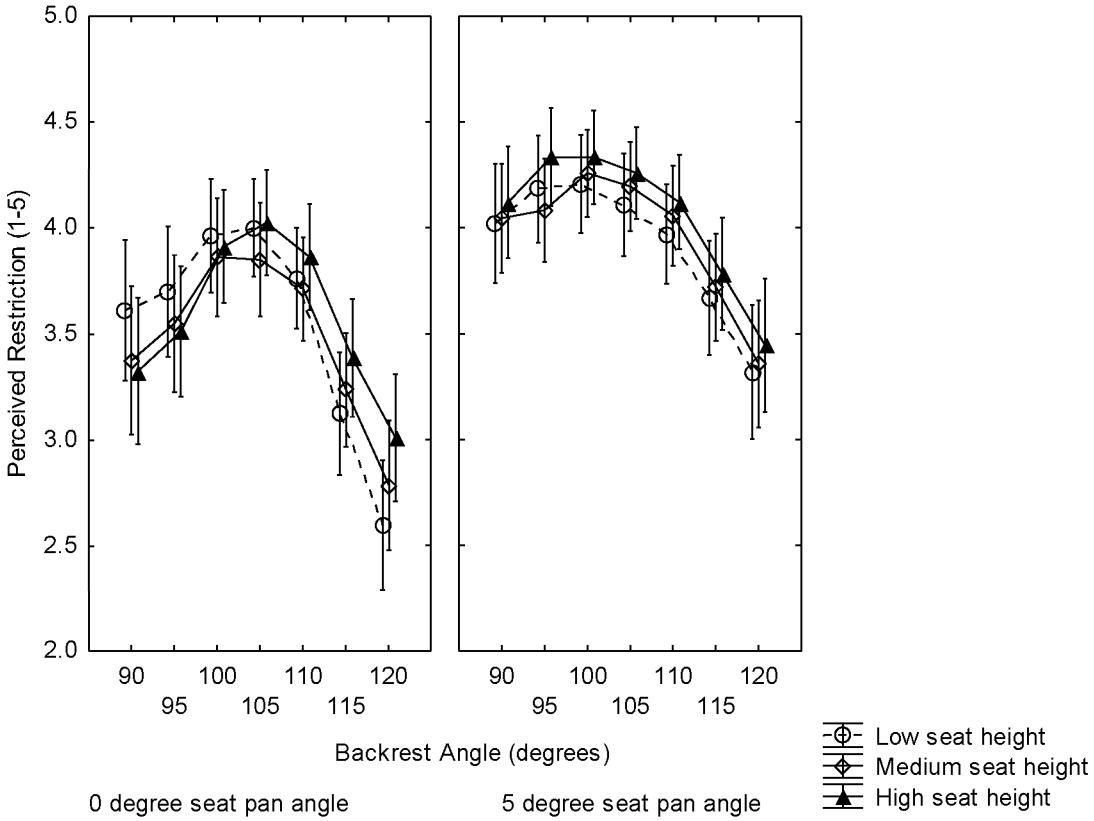

Figure 11: The effect of seat pan angle, seat height and backrest angle on perceived restriction {1=very restricted; 5=not at all restricted}. Error bars denote 95% confidence interval.

Seat pan angle, seat height and backrest angle significantly affected the participants' perceived restriction at chest height (Table 9). Perceived restriction decreased as the backrest reclined from 90 to 100/105 degrees at all seat heights and seat pan angles. After 100/105 degrees, the amount of restriction experienced increased. With regards to seat pan angle, the perceived restriction of the participants was significantly lower with a 5 degree seat pan angle compared to a 0 degree seat pan angle. Seat height did not significantly affect the participants' perceived restriction (Figure 11).

The effects of seating conditions on ease of seat access

Time taken to sit down

Table 10: Statistical significance (error probability) for time taken to sit down, affected by seat pan angle, seat height and backrest angle. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	p=0.032
Seat Height	p=0.009
Backrest Angle	p<0.001
Seat Pan Angle x Seat Height	p=0.234
Seat Pan Angle x Backrest Angle	p=0.015
Seat Height x Backrest Angle	p=0.037
Seat Pan Angle x Seat Height x Backrest Angle	p=0.471

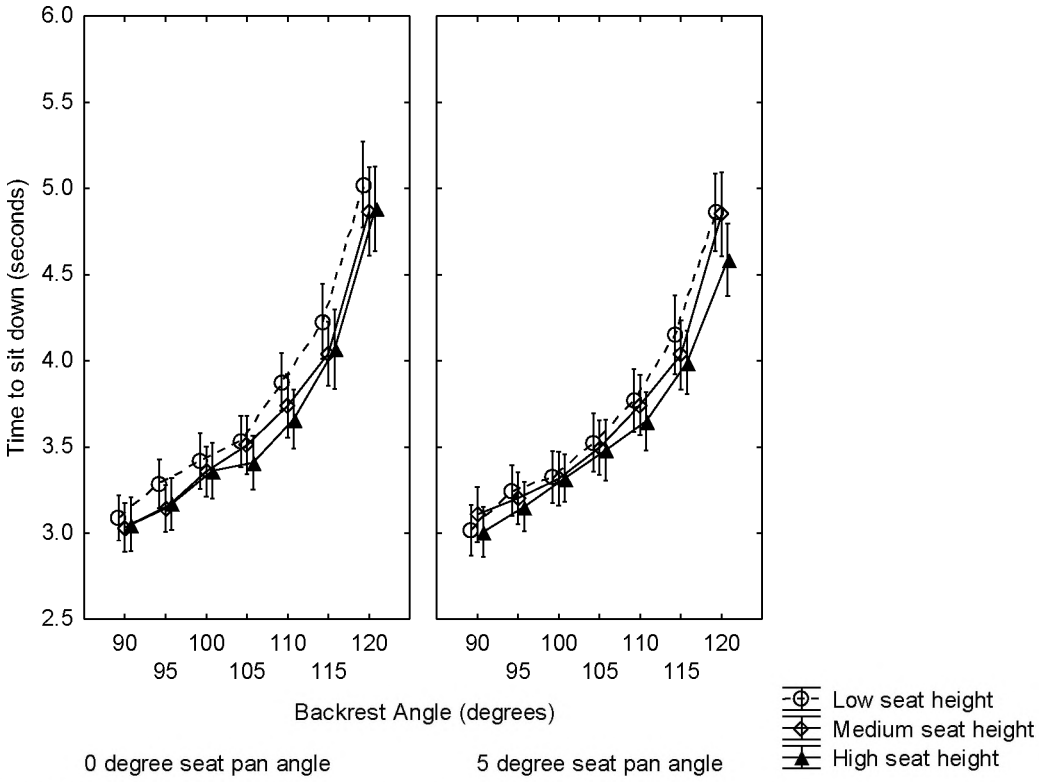

Figure 12: The effect of seat pan angle, seat height and backrest angle on time taken to sit down. Error bars denote 95% confidence interval.

Seat pan angle, seat height and backrest angle significantly affected the participants' time taken to sit down (Table 10). At all seat heights and seat pan angles, the participants' time taken to sit down increased as the backrest angle increased from 90 to 120 degrees. At a 0 degree seat pan angle, the time taken to sit down was significantly slower than with a 5 degree seat pan angle. With regards to seat height, a low seat height resulted in significantly greater access times compared to a medium and high seat height (Figure 12).

Ease of seat access rating

The participants rated how easily they felt they were able to access their seats on a rating scale of 1 to 5, with 1 being very difficult to access and 5 being very easy to access.

Table 11: Statistical significance (error probability) for ease of seat access rating, affected by seat pan angle, seat height and backrest angle. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	p=0.305
Seat Height	p=0.374
Backrest Angle	p<0.001
Seat Pan Angle x Seat Height	p=0.252
Seat Pan Angle x Backrest Angle	p<0.001
Seat Height x Backrest Angle	p=0.296
Seat Pan Angle x Seat Height x Backrest Angle	p=0.642

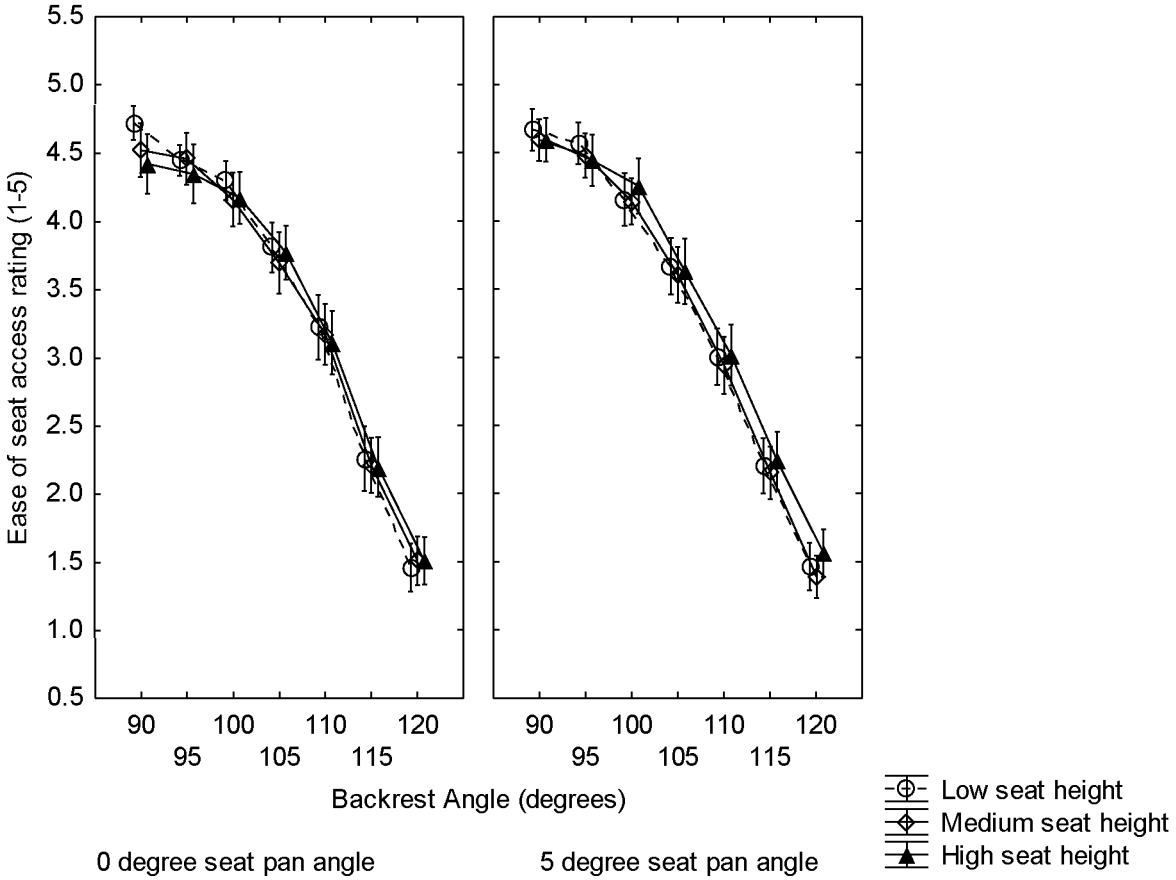

Figure 13: The effect of seat pan angle, seat height and backrest angle on ratings of ease of seat access {1=very difficult to access; 5=very east to access}. Error bars denote 95% confidence interval.

Seat pan angle and backrest angle significantly affected the participants' ease of seat access ratings (Table 11). At all seat heights and seat pan angles, the participants rated their ease of seat access as more difficult as the backrest angle reclines from 90 to 120 degrees. Seat pan angle and backrest angle significantly affected the participants' ease of seat access ratings. Seat pan angle and seat height produced no significant changes in ratings of ease of seat access (Figure 13).

The effects of seating conditions on preferred backrest angle

From the comfort ratings of the 42 seating conditions, it was determined which backrest angle was considered the most comfortable for each seat pan angle and seat height. From this, the participants rated 6 seating conditions, consisting of one preferred backrest angle for each seat pan angle and seat height. The most preferred backrest angle was determined as Denel are considering the use of aircraft seats with a non-adjustable backrest angle. Therefore, it was necessary to determine how seat pan angle and seat height affect the angle of the backrest most preferred by the participants. This was also considered important to measure as it was thought that seat height would affect the preferred angle of the backrest. If a high seat height resulted in a more upright backrest angle, this would save space on the aircraft cabin.

Table 12: Statistical significance (error probability) for the preferred backrest angle, affected by seat pan angle and seat height. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	$p<0.001$
Seat Height	$p=0.004$
Seat Pan Angle x Seat Height	$p=0.527$

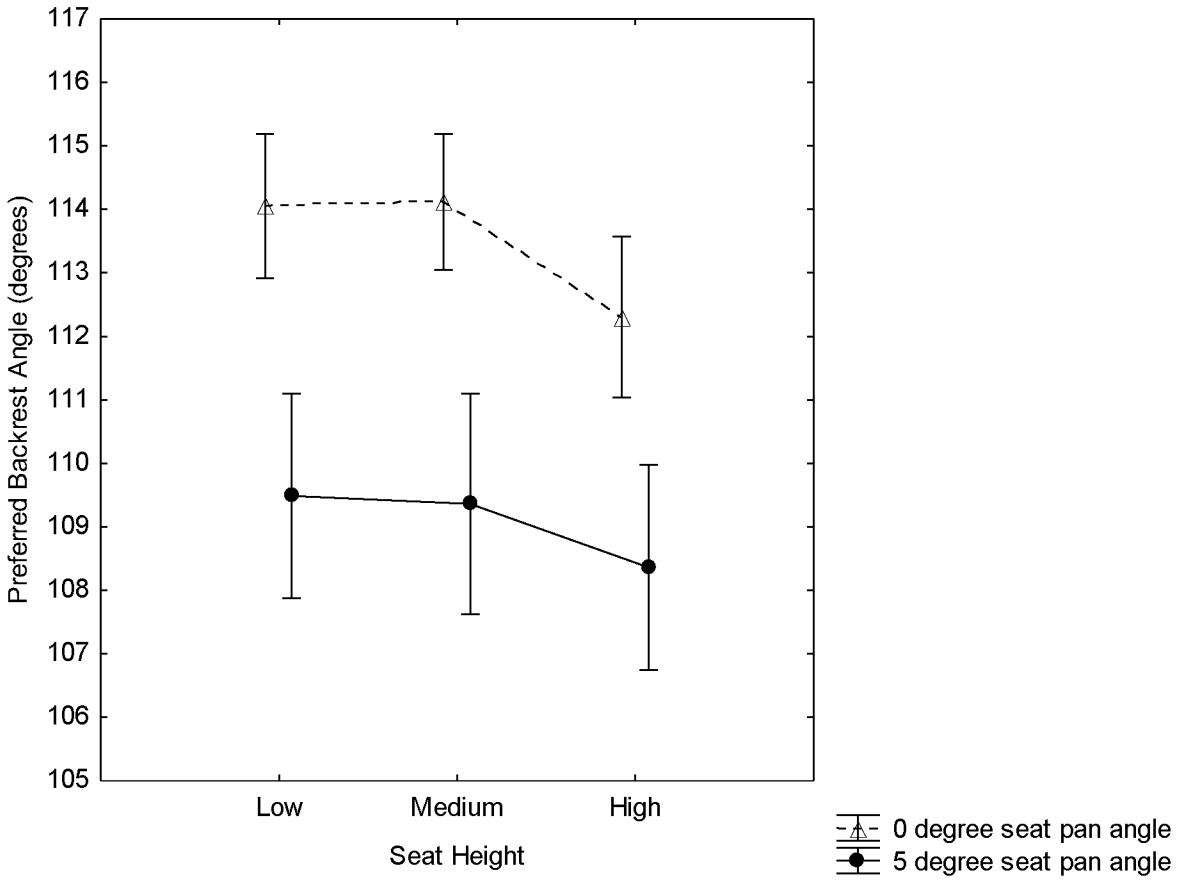

Figure 14: The effect of seat pan angle and seat height on participants' preferred backrest angle. Error bars denote 95% confidence interval.

With regards to seat pan angle, participants' preferred a more reclined backrest angle with a 0 degree seat pan angle. This was significantly different to a 5 degree seat pan angle, where a more upright backrest angle was preferred. With regards to seat height, at both a 0 and a 5 degree seat pan angle, a significantly more upright backrest angle was preferred with a high seat height compared to a low and medium seat height angle (Figure 14).

The effects of seating conditions on comfort ratings

The participants were required to rate the comfort of 6 seating conditions. These consisted of the preferred backrest angle for each seat pan angle and seat height. An absolute rating scale was used to measure comfort, ranging from 0 to 10.

Table 13: Statistical significance (error probability) for comfort, affected by seat pan angle and seat height. Highlighted blocks denote statistical significance ($p<0.05$).

	Effects
Seat Pan Angle	p<0.001
Seat Height	p<0.001
Seat Pan Angle x Seat Height	p=0.163

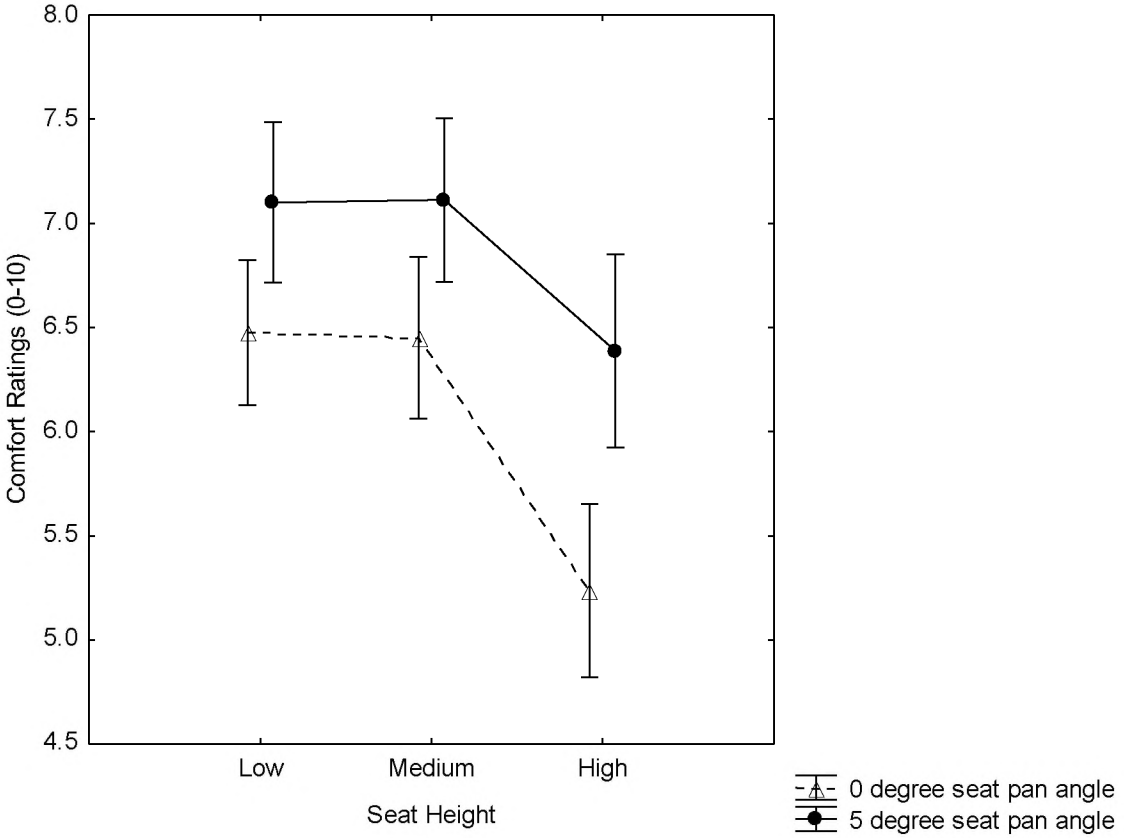

Figure 15: The effect of seat pan angle, seat height and preferred backrest angle on comfort ratings. Error bars denote 95% confidence interval.

At both a 0 and 5 degree seat pan angle, comfort ratings were significantly lower at a high seat height compared to a low and medium seat height. In general, a 5 degree seat pan angle produced significantly greater comfort ratings compared to a 0 degree seat pan angle (Figure 15).

INDIVIDUAL FACTORS

The covariates included in this study consisted of age, sex, stature, body mass, BMI and lower leg length. To analyse the results of the covariates, the participants were split into different groups for each covariate. This can be seen in Table 14 below.

Table 14: The covariates measured, the category of covariates and the number of participants in each category.

Covariate	Category		Number of participants
Age	18-30 years		20 Males 20 Females
	31-60 years		20 Males 20 Females
Stature (cm)	Short	151.9-163.9	18
	Medium	164.3-176.1	40
	Tall	177-189.4	20
Body Mass (kg)	Low	41.8-62.7	25
	Medium	64.2-85.2	45
	High	89.5-125.8	8
BMI	Low	18.1-24.9	38
	Medium	25.1-29.9	25
	High	30.1-37.7	15
Lower Leg Length (cm)	Short	44-48	12
	Medium	49-53	41
	Tall	54-59	25

The effects of the individual factors for all 80 participants were included in this study. However, it must be noted that these factors are not independent from each other as they do correlate to some extent, for example age and BMI. It should also be known that statistical power of the results may be compromised for groups with small numbers of participants. The unequal groups were accepted as the effects were not a central part of this study, but rather a side effect of studying a representative sample of participants.

The effects of individual factors on comfort ratings

Table 15: Statistical significance (error probability) for covariate effects on comfort ratings. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length (cm)
Main effect	p=0.194	p=0.039	p=0.261	p=0.041	p=0.101	p=0.178
Seat pan angle x covariate	p=0.897	p=0.196	p=0.599	p=0.503	p=0.508	p=0.993
Seat height x covariate	p=0.438	p=0.902	p=0.930	p=0.779	p=0.768	p=0.808
Backrest angle x covariate	p=0.922	p=0.333	p=0.609	p=0.258	p=0.374	p=0.487
Seat pan angle x Seat height x covariate	p=0.546	p=0.537	p=0.892	p=0.727	p=0.658	p=0.421
Seat pan angle x Backrest angle x covariate	p=0.028	p=0.739	p=0.042	p=0.032	p=0.615	p=0.107
Seat height x Backrest angle x covariate	p=0.667	p=0.294	p=0.428	P=0.478	p=0.679	p=0.276
Seat pan angle x Seat height x Backrest angle x covariate	p=0.640	p=0.996	p=0.737	p=0.453	p=0.973	p=0.831

The following graphs displayed will only consist of the significant effects. However, significant effects consisting of more than two factors will not be included due to the inability to transfer these into seat design, as well as the complex interpretation of results consisting of more than two factors.

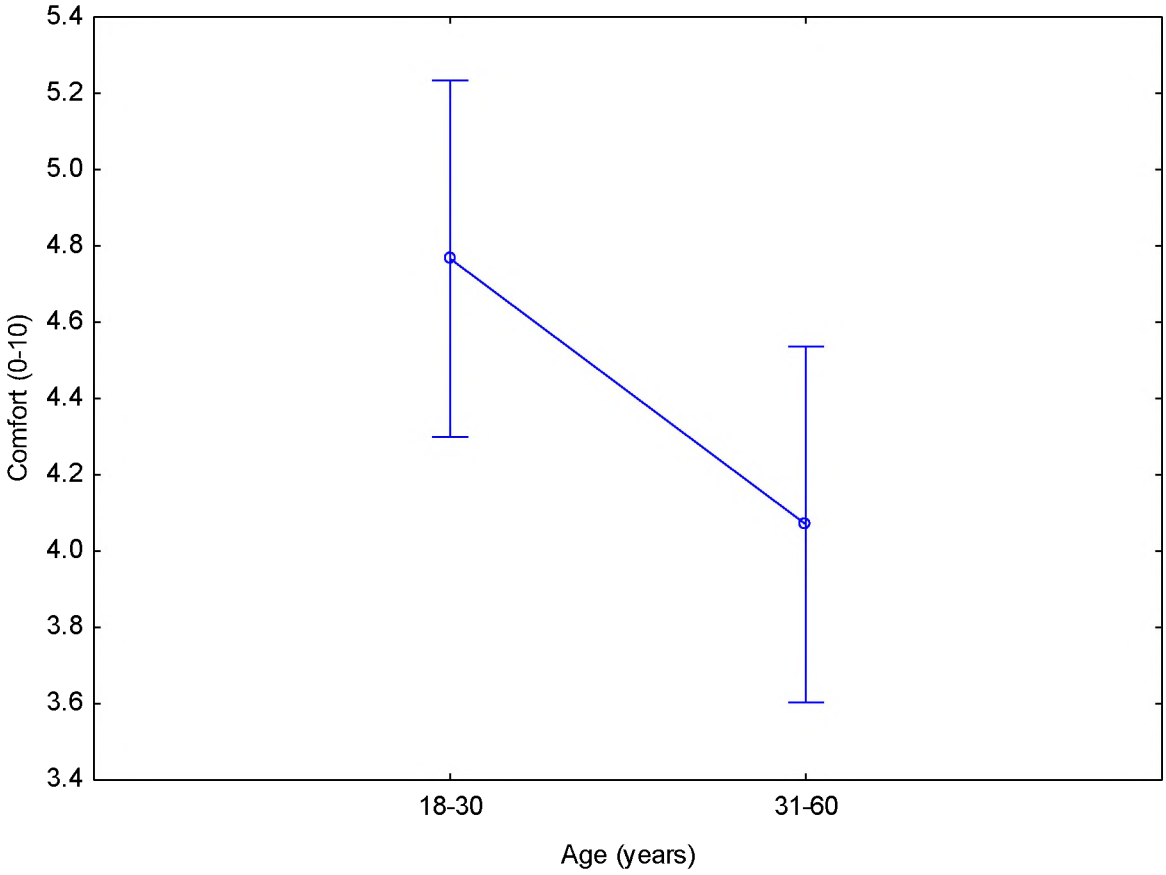

Figure 16: The effect of age on comfort ratings. Error bars denote 95% confidence interval.

Participants in the 18-30 year age category gave significantly greater comfort ratings compared to participants in the 31-60 year age category (Figure 16).

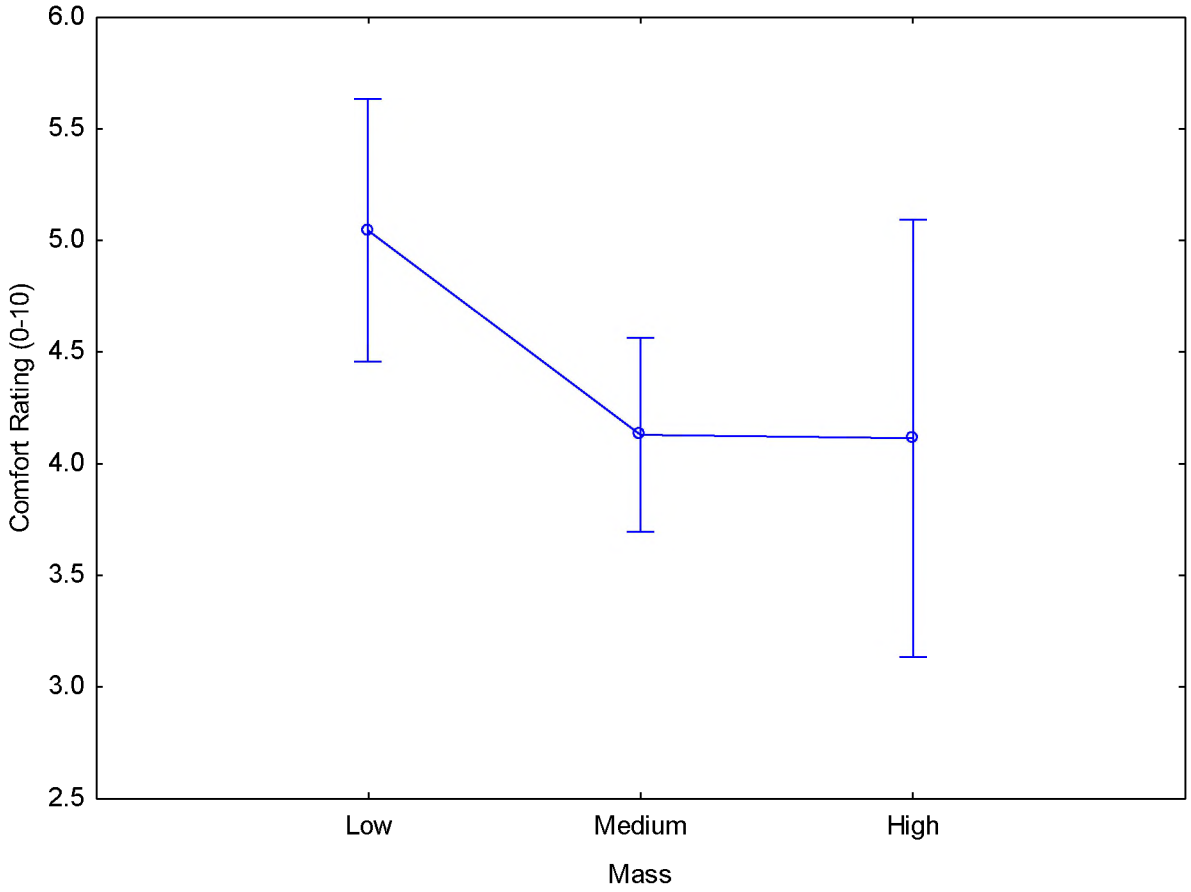

Figure 17: The effect of body mass on comfort ratings. Error bars denote 95% confidence interval.

Participants with a high and medium mass produced significantly lower comfort ratings compared to participants with a low body mass (Figure 17).

The effects of individual factors on legroom

Table 16: Statistical significance (error probability) for legroom, affected by the covariates. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length cm)
Main Effects	p=0.057	p=0.053	p=0.084	p=0.508	p=0.978	p=0.071
Seat pan angle x Covariate	p=0.117	p=0.089	p=0.226	p=0.495	p=0.037	p=0.076
Seat height x Covariate	p=0.264	p=0.630	p=0.508	p=0.840	p=0.418	p=0.450
Backrest angle x Covariate	p=0.930	p=0.004	p=0.756	p=0.044	p=0.121	p=0.994
Seat pan angle x Seat height x Covariate	p=0.465	p=0.404	p=0.193	p=0.459	p=0.788	p=0.584
Seat pan angle x Backrest angle x Covariate	p=0.739	p=0.658	p=0.371	p=0.251	p<0.001	p=0.168
Seat height x Backrest angle x Covariate	p=0.334	p=0.003	p=0.707	p=0.072	p=0.053	p=0.041
Seat pan angle x Seat height x Backrest angle x Covariate	p=0.760	p=0.751	p=0.493	p=0.953	p=0.485	p=0.963

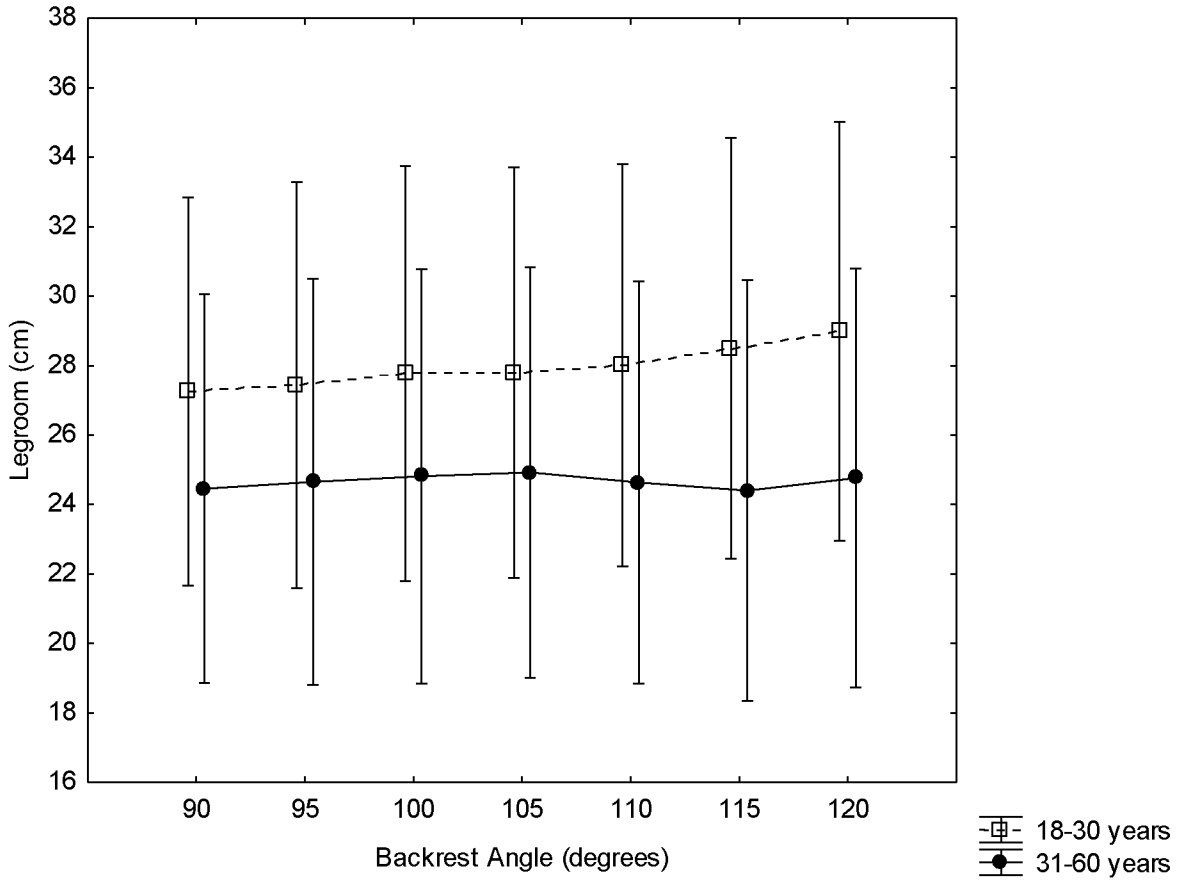

Figure 18: The effect of age and backrest angle on the amount of space used for legroom. Error bars denote 95% confidence interval.

The effect of backrest angle on space used for legroom was significantly affected by age (Figure 18). Participants in the 18-30 year age category used more space for legroom compared to participants in the 31-60 year age category.

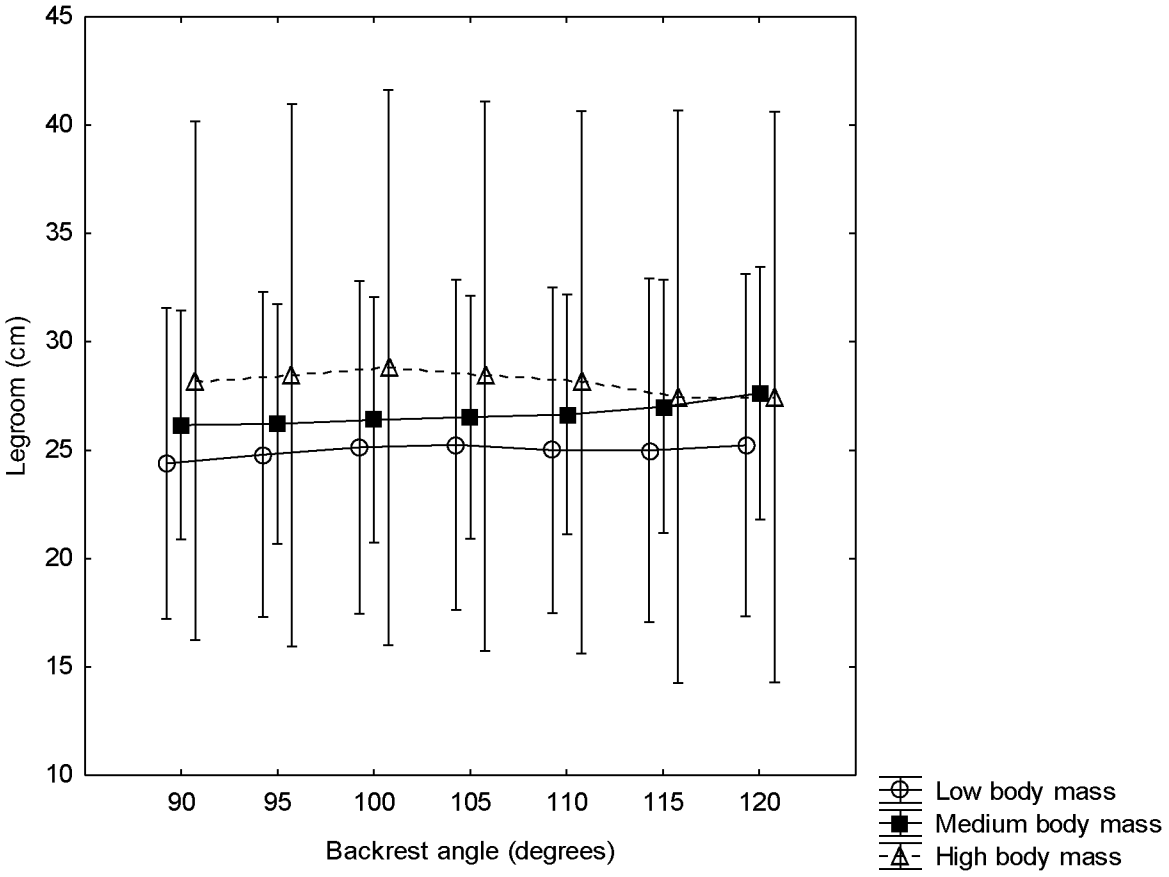

Figure 19: The effect of body mass and backrest angle on the amount of space used for legroom. Error bars denote 95% confidence interval.

The effect of backrest angle on space used for legroom was significantly affected by body mass (Figure 19). From backrest angles ranging from 90 to 110 degrees, participants with a high body mass used more space for legroom compared to participants with a low and medium body mass. At a 115 and 120 degree backrest angle, participants with a low body mass used less space for legroom compared to participants of a medium and high body mass.

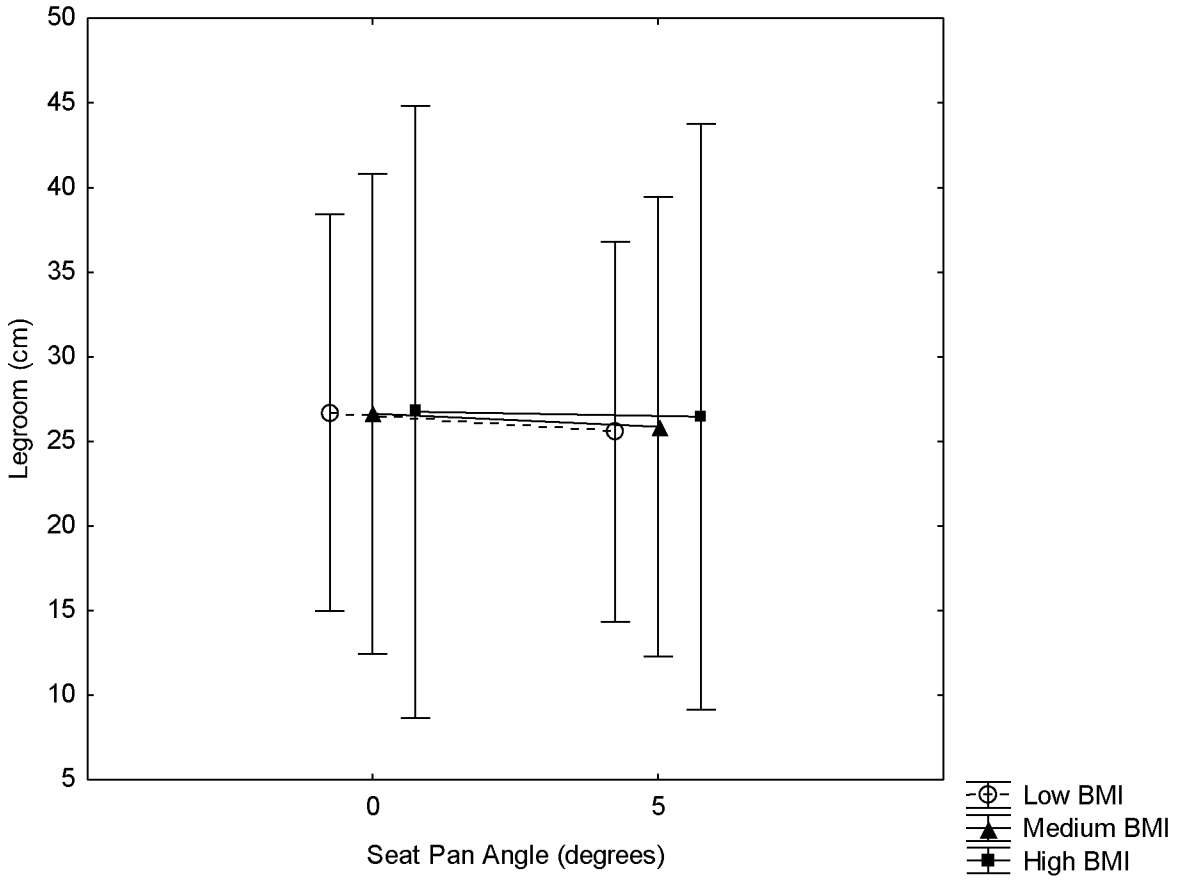

Figure 20: The effect of BMI and seat pan angle on the amount of space used by the participants for legroom. Error bars denote 95% confidence interval.

The effect of seat pan angle on space used for legroom was significantly affected by BMI (Figure 20). Although the statistical significance can be outlined, the practical effects were minimal as legroom varies by 1-2cm.

The effects of individual factors on perceived restriction

Table 17: Statistical significance (error probability) ratings of perceived restriction, affected by the covariates. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length (cm)
Main Effects	p=0.786	p=0.347	p=0.309	p=0.164	p=0.449	p=0.101
Seat pan angle x Covariate	p=0.724	p=0.777	p=0.212	p=0.680	p=0.996	p=0.364
Seat height x Covariate	p=0.293	p=0.512	p=0.703	p=0.350	p=0.229	p=0.959
Backrest angle x Covariate	p=0.108	p=0.307	p<0.001	p=0.217	p=0.867	p=0.047
Seat pan angle x Seat height x Covariate	p=0.022	p=0.411	p=0.352	p=0.034	p=0.121	p=0.133
Seat pan angle x Backrest angle x Covariate	p=0.439	p=0.082	p=0.922	p=0.340	p<0.001	p=0.515
Seat height x Backrest angle x Covariate	p=0.716	p=0.261	p=0.854	p=0.500	p=0.560	p=0.493
Seat pan angle x Seat height x Backrest angle x Covariate	p=0.070	p=0.640	p=0.215	p<0.001	p=0.054	p=0.599

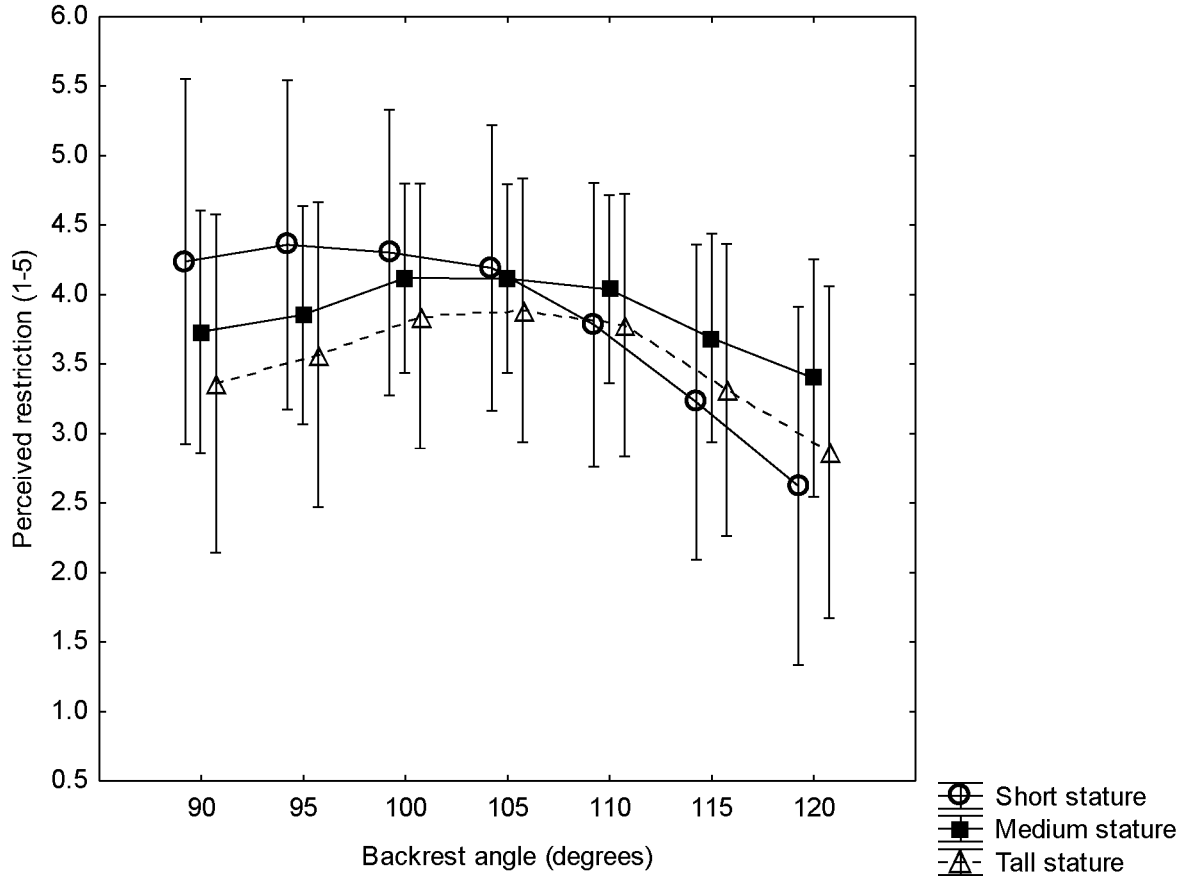

Figure 21: The effect of stature and backrest angle on the participants' perceived restriction at chest height. Error bars denote 95% confidence interval.

The effect of backrest angle on the participants' perceived restriction was significantly affected by stature (Figure 21). At backrest angles ranging from 90 to 100 degrees, short participants experienced less restriction at chest height compared to participants of a medium and tall stature. Tall participants experienced the most restriction at these backrest angles. At a 105 degree backrest angle, there was little difference in the amount of restriction experienced between short, medium and tall participants. From a 110 to 120 degree backrest angle, the restriction experienced by all participants increased. However, short participants experienced a greater increase in restriction compared to participants of a medium and tall stature.

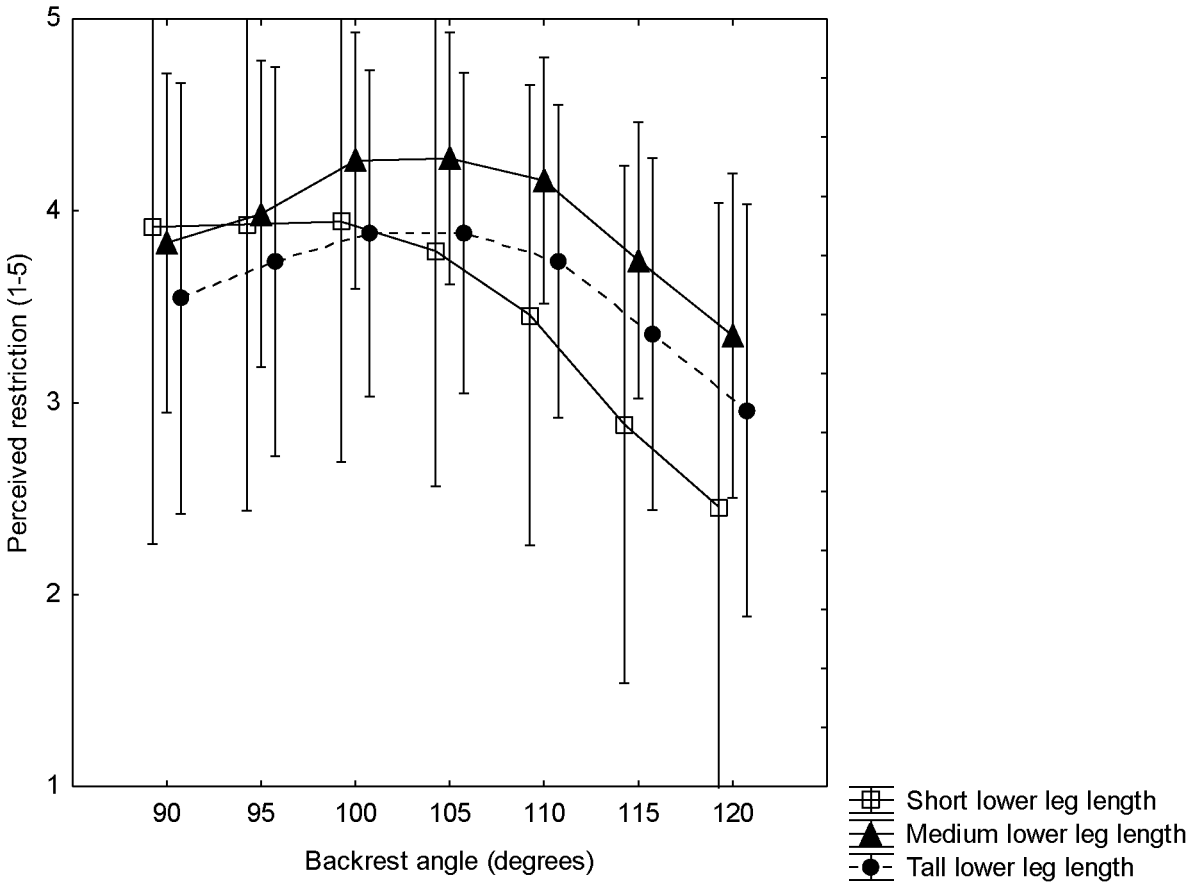

Figure 22: The effect of lower leg length and backrest angle on the participants' perceived restriction at chest height {1=very restricted; 5=not at all restricted}. Error bars denote 95% confidence interval.

The effect of backrest angle on the participants' perceived restriction was significantly affected by lower leg length (Figure 22). At a 90 and 95 degree backrest angle, participants with a tall lower leg length experienced greater restriction compared to participants with a short and medium lower leg length. From 105 to 120 degrees, the restriction experienced by the participants' increased. However, participants with a short lower leg length experienced greater restriction compared to participants with a medium and tall lower leg length.

The effects of individual factors on ease of seat access

Time taken to sit down

Table 18: Statistical significance (error probability) for time taken to sit down, affected by the covariates. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length (cm)
Main Effect	p=0.980	p=0.602	p=0.918	p=0.304	p=0.020	p=0.076
Seat pan angle x Covariate	p=0.636	p=0.741	p=0.521	p=0.668	p=0.570	p=0.098
Seat height x Covariate	p=0.624	p<0.001	p=0.159	p=0.821	p=0.764	p=0.585
Backrest angle x Covariate	p=0.878	p=0.997	p=0.002	p=0.182	p=0.915	p=0.733
Seat pan angle x Seat height x Covariate	p=0.816	p=0.745	p=0.794	p=0.800	p=0.134	p=0.991
Seat pan angle x Backrest angle x Covariate	p=0.408	p=0.343	p=0.505	p=0.419	p=0.805	p=0.467
Seat height x Backrest angle x Covariate	p=0.027	p=0.047	p=0.193	p=0.168	p=0.762	p=0.866
Seat pan angle x Seat height x Backrest angle x Covariate	p=0.538	p=0.544	p=0.567	p=0.194	p=0.801	p=0.236

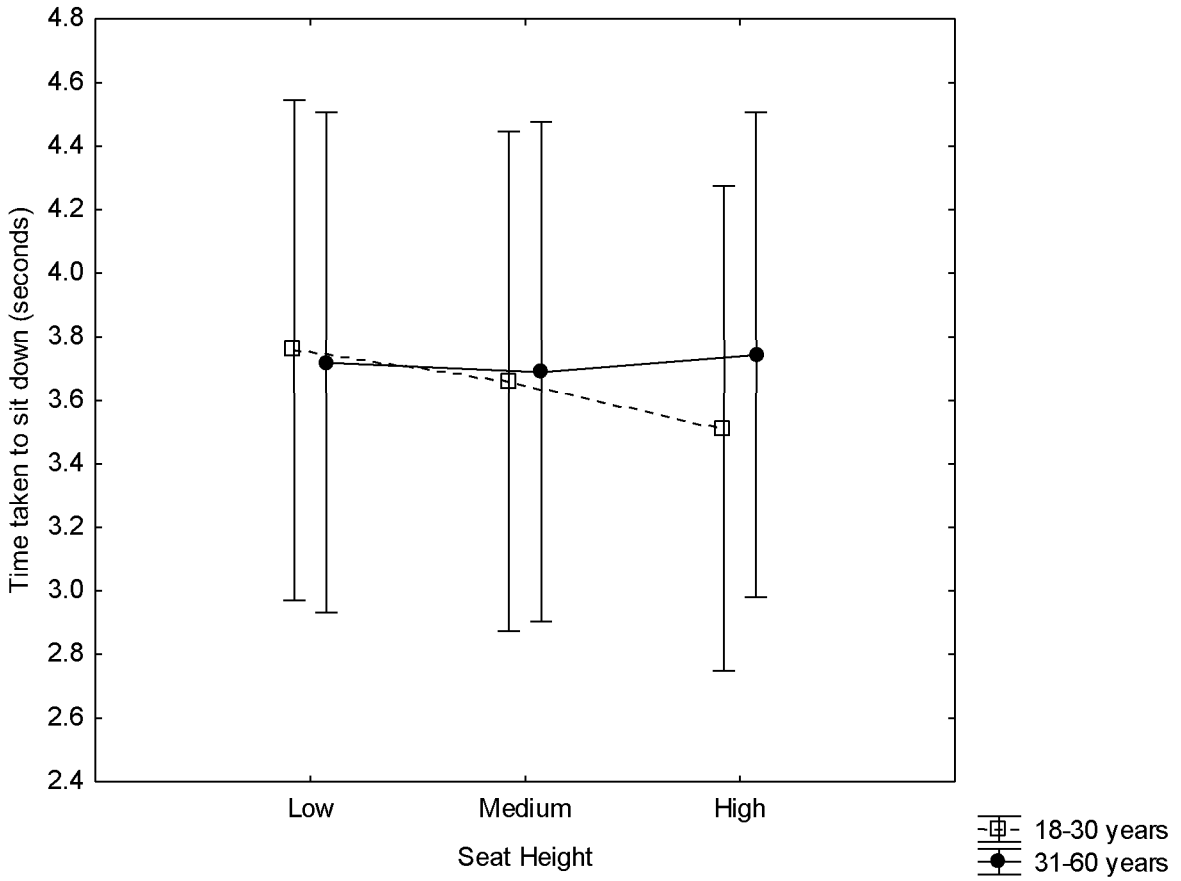

Figure 23: The effect of age and seat height on the participants' time taken to sit down. Error bars denote 95% confidence interval.

At a high seat height, participants in the 18-30 year age category took less time to access their seats than participants in the 31-60 year age category. At a low and medium seat height there was no difference in the time taken for participants in different age categories to sit down (Figure 23).

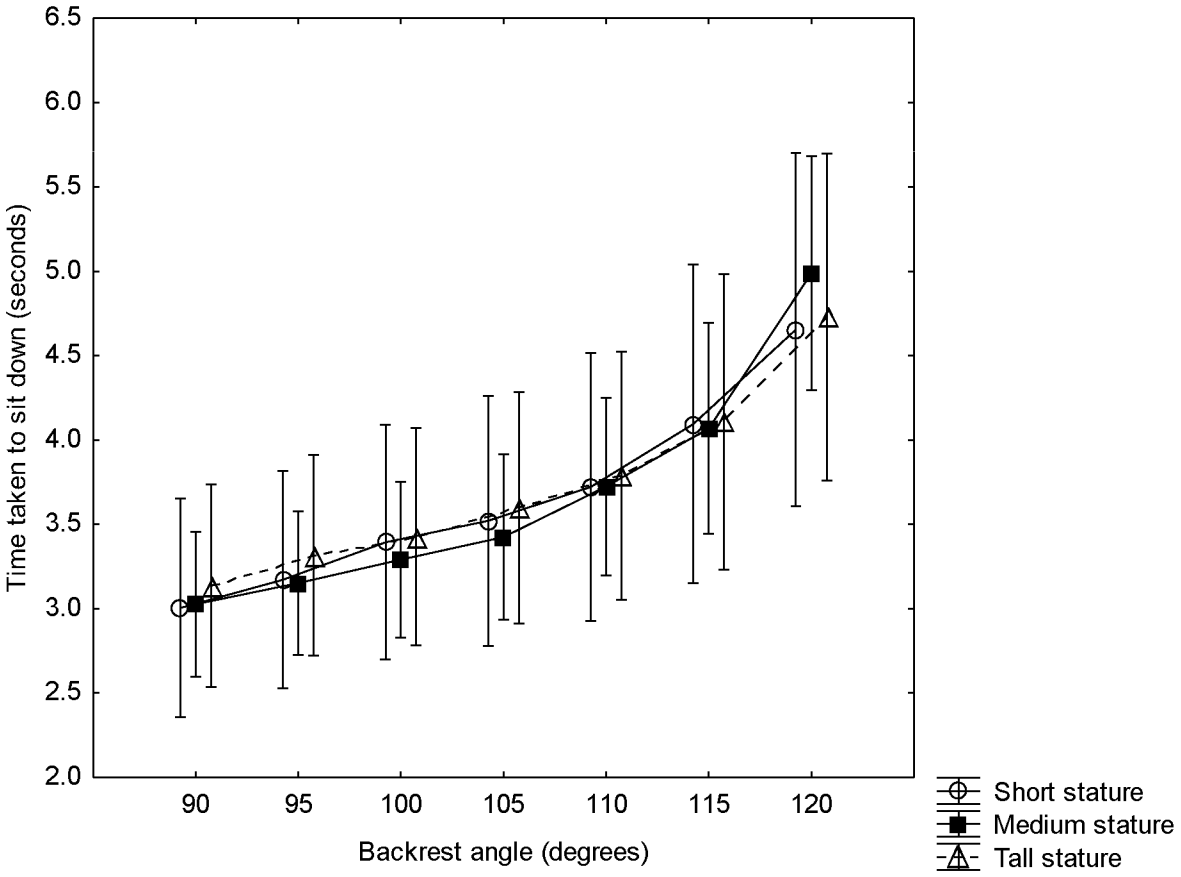

Figure 24: The effect of stature and backrest angle on the participants' time taken to sit down. Error bars denote 95% confidence interval.

The effect of backrest angle on the participants' time taken to sit down was significantly affected by stature (Figure 24). However, the amount of time taken to sit down was only significantly slower at a 120 degree backrest angle. While the time to sit down does increased from a 90 to a 115 degree backrest angle, this was not significant.

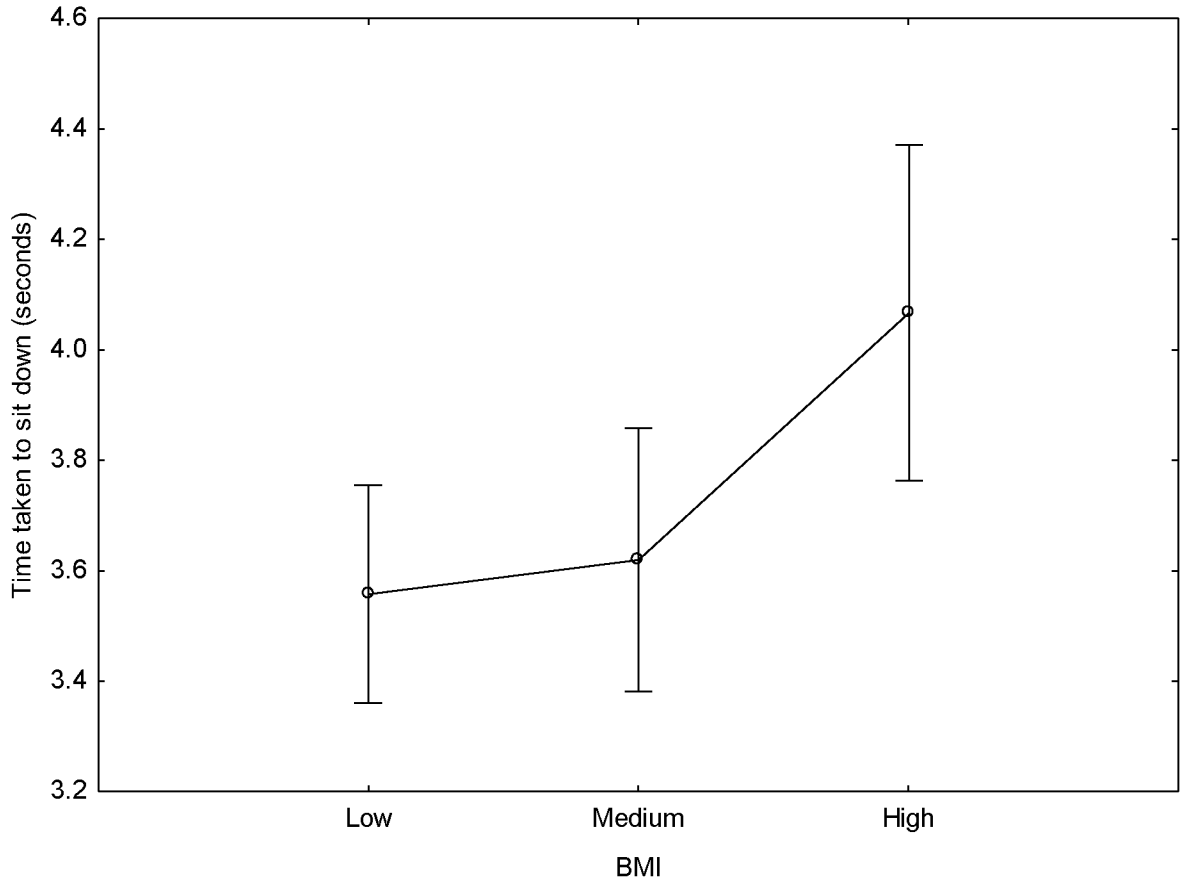

Figure 25: The effect of BMI on the participants' time taken to sit down. Error bars denote 95% confidence interval.

BMI was found to have a significant effect on the participants' time taken to sit down (Figure 25). Participants with a high BMI took longer to access their seat compared to participants with a low and medium BMI.

Ease of seat access rating

Table 19: Statistical significance (error probability) for ratings of ease of seat access, affected by the covariates. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length (cm)
Main Effects	p=0.432	p=0.543	p=0.664	p=0.065	p=0.612	p=0.428
Seat pan angle x Covariate	p=0.304	p=0.091	p=0.269	p=0.777	p=0.203	p=0.002
Seat height x Covariate	p=0.938	p=0.385	p=0.918	p=0.056	p=0.621	p=0.748
Backrest angle x Covariate	p=0.557	p=0.051	p=0.999	p=0.188	p=0.699	p=1.000
Seat pan angle x Seat height x Covariate	p=0.603	p=0.179	p=0.091	p=0.199	p=0.345	p=0.878
Seat pan angle x Backrest angle x Covariate	p=0.785	p=0.110	p=0.271	p=0.432	p=0.407	p=0.891
Seat height x Backrest angle x Covariate	p=0.083	p=0.694	p=0.968	p=0.719	p=0.112	p=0.833
Seat pan angle x Seat height x Backrest angle x Covariate	p=0.308	p=0.008	p=0.984	p=0.901	p=0.008	p=0.895

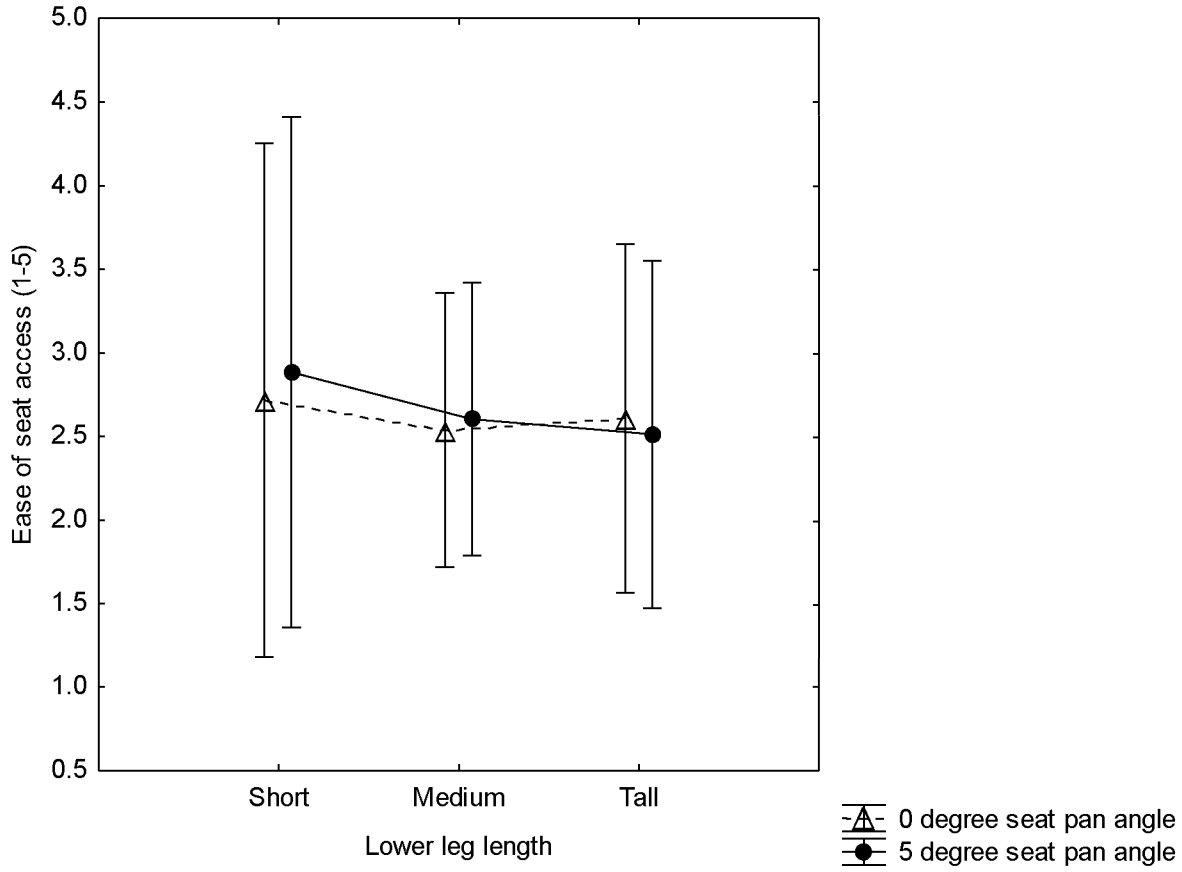

Figure 26: The effect of lower leg length and seat pan angle on the participants' rating of ease of seat access {1 = very difficult to access; 5 = very easy to access}. Error bars denote 95% confidence interval.

The effect of seat pan angle on ratings of ease of seat access was significantly affected by lower leg length (Figure 26). At both a 5 degree and 0 degree seat pan angle, participants with a short lower leg length rated ease of seat access as more difficult than participants with a medium and tall lower leg length. Participants with a short lower leg length rated ease of seat access as more difficult with a 5 degree seat pan angle compared to a 0 degree seat pan angle. A 0 and 5 degree seat pan angle produced no differences in ease of seat access ratings between participants of a medium and tall lower leg length.

The effects of individual factors on preferred backrest angle

The covariates; sex, age, stature, body mass, BMI and lower leg length were analysed to determine their effects on the 6 seating conditions, consisting of the preferred backrest angle for each seat pan angle and seat height.

Table 20: statistical significance (error probability) for the preferred backrest angle for each seat pan angle and seat height, affected by the covariates. Highlighted blocks denote statistical significance ($p<0.05$).

	Covariates					
	Sex	Age	Stature (cm)	Body Mass (kg)	BMI	Lower Leg Length (cm)
Main Effect	p=0.524	p=0.972	p=0.209	p=0.794	p=0.828	p=0.551
Seat pan angle x covariate	p=0.041	p=0.202	p=0.008	p=0.010	p=0.246	p=0.147
Seat height x covariate	p=0.103	p=0.271	p=0.018	p=0.023	p=0.046	p=0.303
Seat pan angle x Seat height x covariate	p=0.435	p=0.803	p=0.336	p=0.744	p=0.176	p=0.760

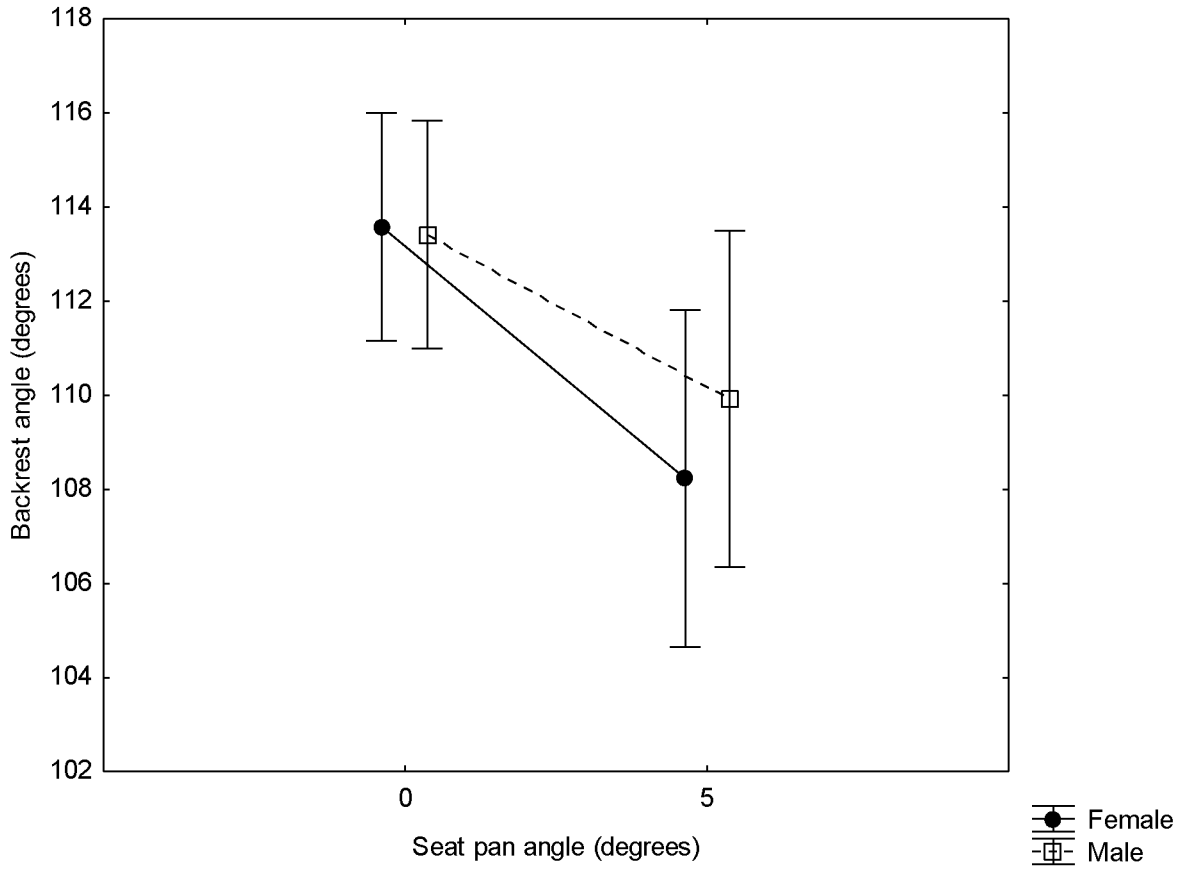

Figure 27: The effect of sex and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

While preferred backrest angle does not depend on sex generally, there was a significant difference with the addition of seat pan angle (Figure 27). At a 5 degree seat pan angle, females preferred a more upright backrest angle compared to males who preferred a more reclined backrest angle. There was no difference in preferred backrest angles between males and females at a 0 degree seat pan angle.

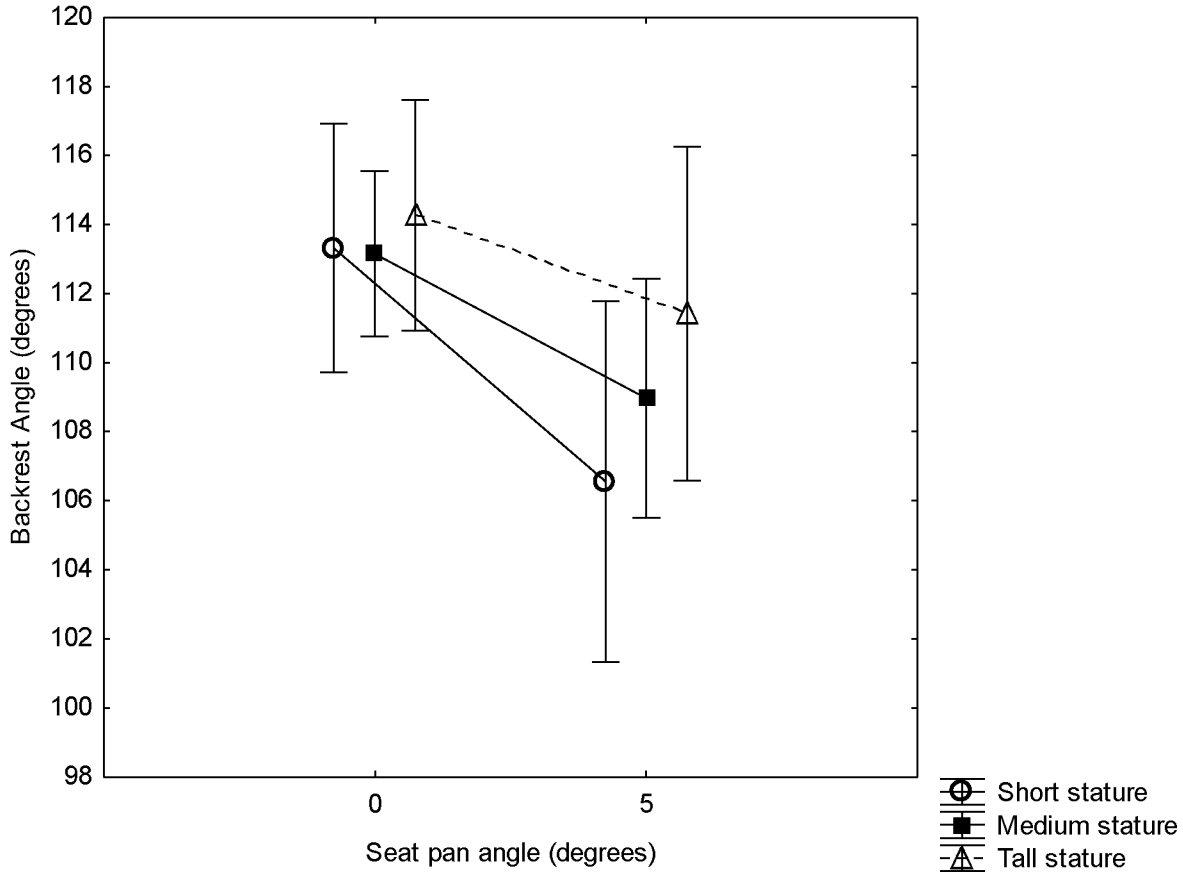

Figure 28: The effect of stature and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

The effect of seat pan angle on preferred backrest angle was significantly affected by stature (Figure 28). At a 5 degree seat pan angle, short participants preferred a more upright backrest angle compared to tall participants who preferred a more reclined backrest angle. The trend was similar with a 0 degree seat pan angle, however the difference between participants of different statures was not as great. While this was significant, it must be noted that stature and sex relate to each other as males are taller than females. Therefore the results found may be due to this interaction.

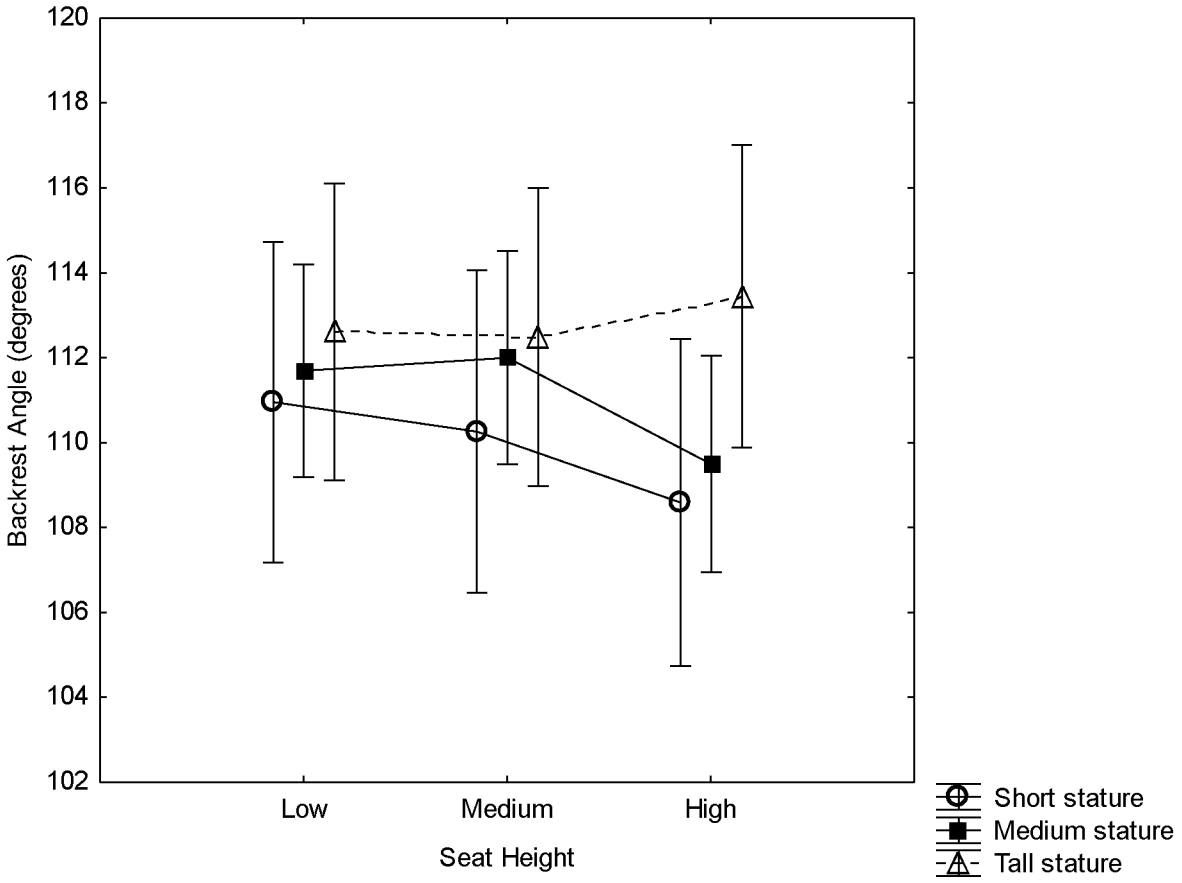

Figure 29: The effect of stature and seat height on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

The effect of seat height on the preferred backrest angle was significantly affected by stature (Figure 29). At a low seat height, participants of a tall stature preferred a more reclined backrest angle compared to participants of a medium and short stature. At a medium seat height, short participants preferred a more upright backrest angle compared to participants of a medium and tall stature. At a high seat height, tall participants preferred an even more reclined backrest angle compared to a low and medium seat height. This was different to participants of a medium and short stature who preferred an even more upright backrest angle at a high seat height.

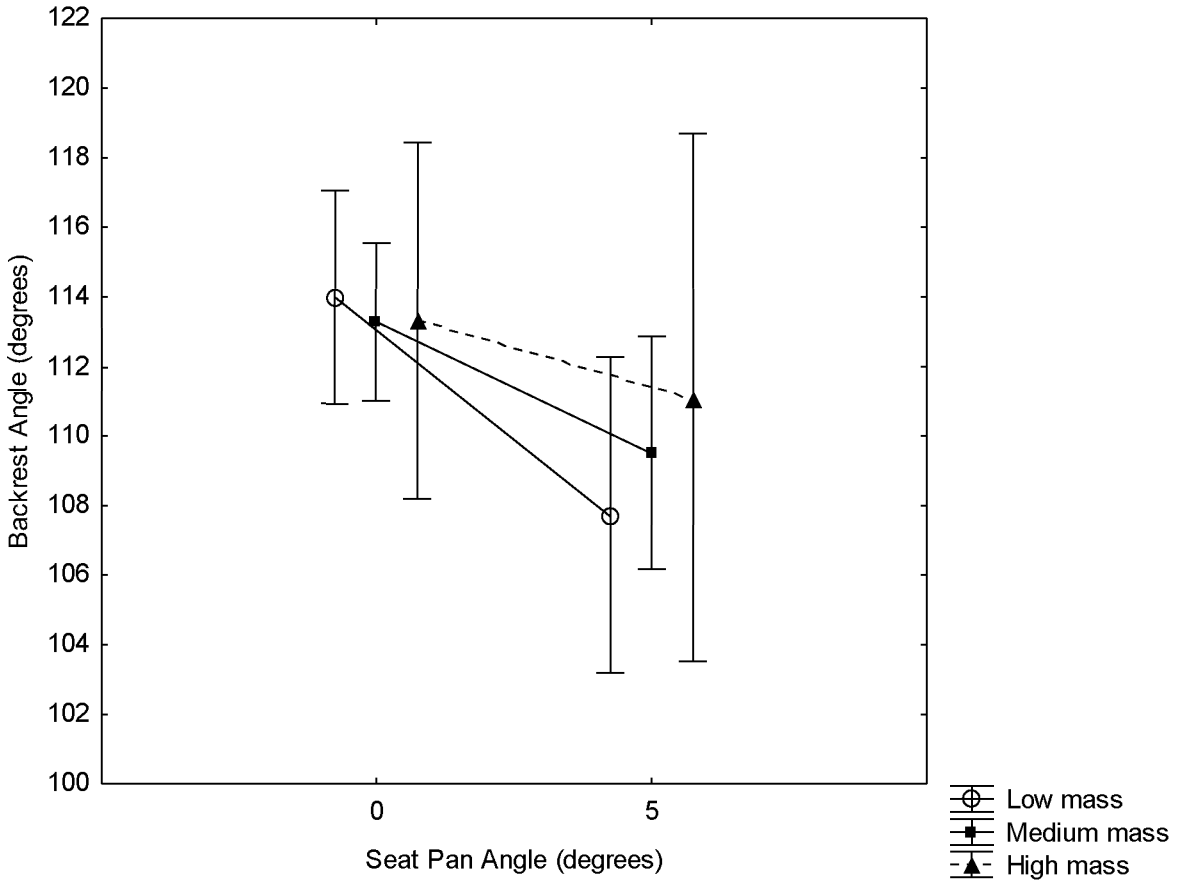

Figure 30: The effect of body mass and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

The effect of seat height on preferred backrest angle was significantly affected by body mass (Figure 30). At a 5 degree seat pan angle, participants with a low body mass preferred a more upright backrest angle compared to participants with a medium and high body mass. There was a non-significant difference in preferred backrest angle between participants of varying body masses at a 0 degree seat pan angle.

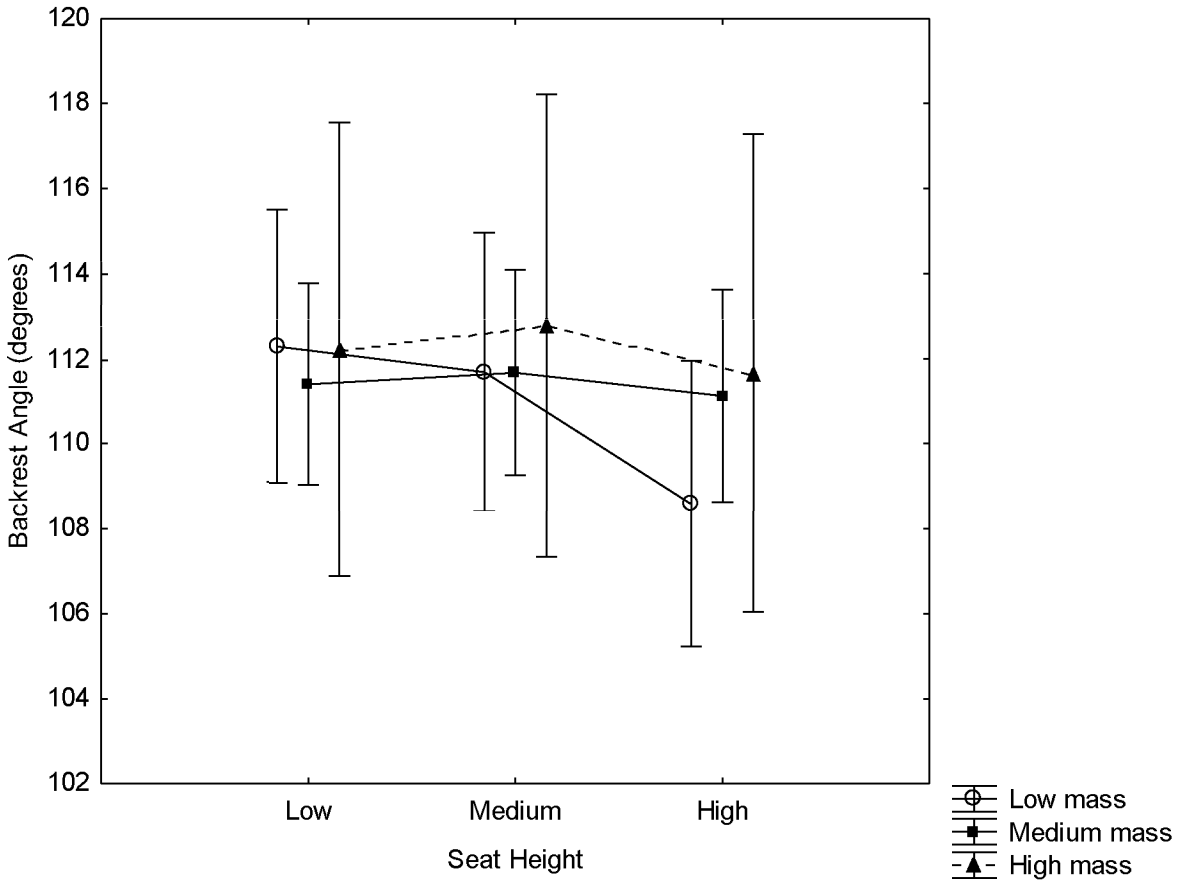

Figure 31: The effect of body mass and seat height on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

The effect of seat height on backrest angle was significantly affected by body mass (Figure 31). At a high seat height, participants with a low body mass preferred a more upright backrest angle compared to participants with a medium and high body mass. At a medium seat height, participants with a high body mass preferred a more reclined backrest angle compared to participants with a low and medium body mass. At a low seat height there was no difference in preferred backrest angle between participants of different body masses.

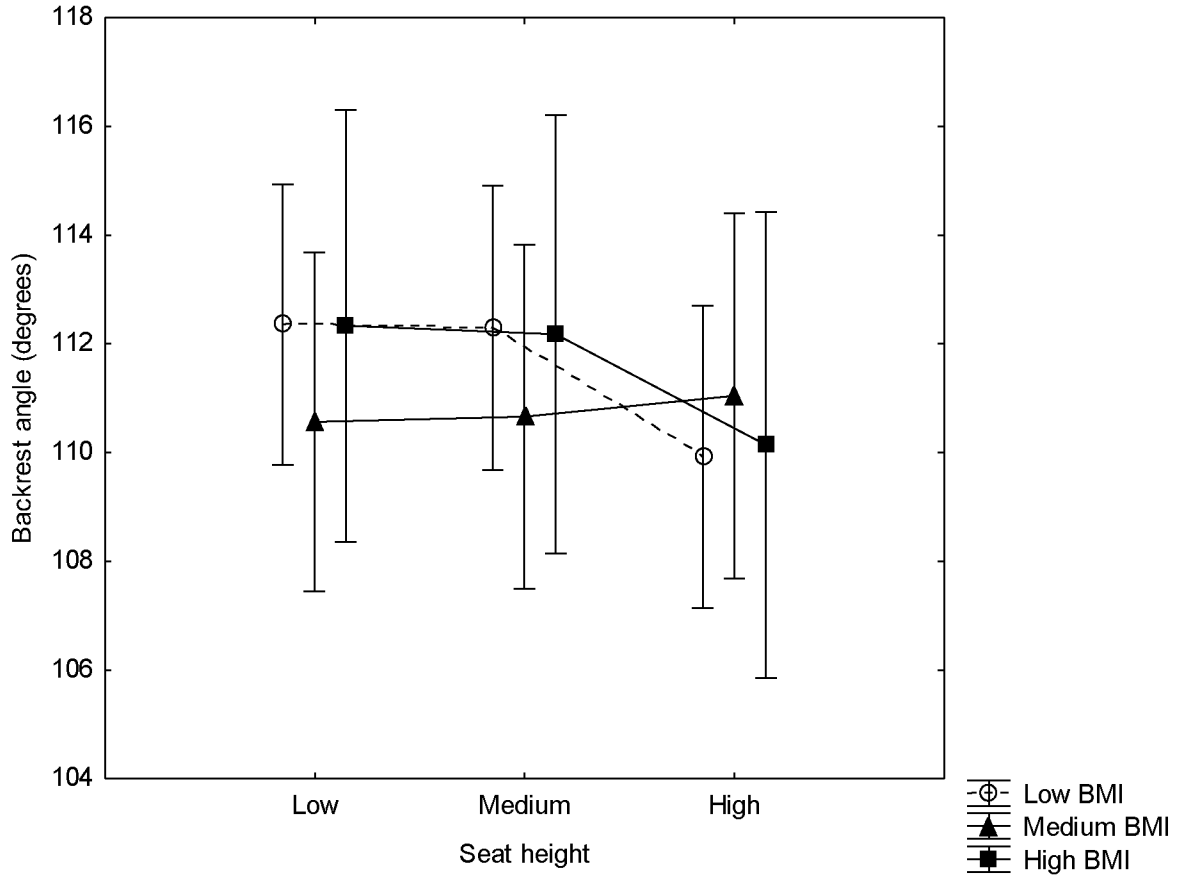

Figure 32: The effect of BMI and seat height on the participants' preferred backrest angle. Error bars denote 95% confidence interval.

The effect of seat height on preferred backrest angle was significantly affected by BMI (Figure 32). Participants with a low and high BMI preferred a more reclined backrest angle at low and medium seat heights compared to participants with a medium BMI. At a high seat height, participants with a low and high BMI preferred a more upright backrest angle compared to participants with a medium BMI.

CHAPTER V
DISCUSSION

This study tested 80 participants. The results from this study showed that seat pan angle, seat height and backrest angle do affect individuals' perceived comfort, ease of seat access, perceived restriction and legroom. It was also found that the participants' preferred backrest angle was affected by seat pan angle and seat height. This study further investigated the effects of the covariates (sex, age, stature, mass, BMI and lower leg length) on the dependent variables and showed that seat factors and some individual characteristics have an effect on the dependent variables.

For this study, the data collection was limited to the Eastern Cape, particularly the Grahamstown community. As a result, the 80 participants were not necessarily an accurate representative of the South African population with regards to stature and weight. The South African Demographic Health Survey (2003) showed that on average, the BMI for men is 23.3kg/m^2, and 27kg/m^2 for females. The average BMI of the males in the 18-30 year and 32-60 year age category were 25.9 kg/m^2 and 28.5 kg/m^2 respectively. This is higher than the BMI of the average male represented in the South African Demographic Health Survey (2003). In this current study, the female participants in the 18-30 year and 31-60 year age category had an average BMI of 24.1 kg/m^2 and 25.5 kg/m^2 respectively. This is slightly lower than the average BMI of South African females. Collecting data from other areas in South Africa would have improved the sample size and the validity of the study, as SARA is a regional aircraft and will be transporting people from all over the country.

THE EFFECTS OF SEAT PAN ANGLE, SEAT HEIGHT AND BACKREST ANGLE ON THE DEPENDENT VARIABLES

The effects of seat pan angle, seat height and backrest angle on comfort ratings

From this study it was found that seat pan angle, seat height and backrest angle had a significant effect on the participants' perceived comfort. These results were similar for the rating of both the 42 seating conditions (Figure 9), as well as for the rating of the last 6 seating conditions (Figure 15).

With regards to the rating of the 42 seating conditions, for all seat heights, at a 0 degree seat pan angle, comfort ratings were greatest with a 115 degree backrest angle. At all seat heights, with a 5 degree seat pan angle, comfort ratings were greatest at a 110 degree backrest angle. Backrest angle was measured from the vertical direction and was set relative to the seat pan angle. Therefore, the backrest angle for a 5 degree seat pan angle was more reclined compared to the same backrest angle for a 0 degree seat pan angle. This means that the most preferred backrest angle at a 5 degree seat pan angle is more upright compared to the most preferred backrest angle at a 0 degree seat pan angle. It should be cognised that this was a short-term study, with the participants only sitting in each seating condition for a maximum of 30 seconds.

With regards to seat height, for both the 42 seating conditions and the last 6 seating conditions (Figure 9 and Figure 15), the participants' comfort ratings were greatest with a low and medium seat height compared to a high seat height. It is probable that at a high seat height, the participants were unable to stretch out their legs, limiting their ability for posture change. This may have led to the lower comfort ratings. With regards to seat pan angle, a 5 degree seat pan angle produced greater comfort ratings compared to a 0 degree seat pan angle. It is possible that at a 0 degree seat pan angle, the participants experienced the feeling of slipping forwards in their seat, resulting in decreased comfort ratings. It is also possible that the participants were used to sitting in a seat with an upward tilting seat pan angle, which would have resulted in feelings of discomfort whilst sitting in a seat with a 0 degree seat pan angle.

It must be noted however, that sitting comfort does depend on other factors, such as the activity being performed whilst sitting (Groenesteijn, 2015). Whilst flying, passengers are not limited to just sitting, but are able to perform several activities such as sleeping, reading, eating and working on laptops. As explained by groenesteijn (2015), performing different activities requires the adoption of different body postures. These different postures, adopted due to the specific task being performed, results in different muscle activation (Groenesteijn, 2015). This is particularly important when considering backrest angle. For example; Nathan-Roberts *et al*. (2008) found that while watching television, individuals preferred a backrest angle of 100 degrees. Park *et al*. (2000) observed postures whilst driving and found that an average backrest angle of 117 degrees was preferred by participants. This means that it would be beneficial to have adjustable seats to accommodate for these factors.

The effect of age on perceived comfort

The results showed that participants ranging between 18-30 years of age gave significantly higher comfort ratings compared to participants ranging between 31-60 years of age (Figure 16). Research has shown that older travellers experience decreases in strength, spatial orientation, mobility and muscle composition (Hertzberg, 1972; McMullin *et al*., 2014). These physiological and biomechanical changes make travelling more difficult, possibly leading to decreases in comfort whilst sitting.

The effect of mass on perceived comfort

Participants with a medium and high mass produced significantly lower comfort ratings compared to participants with a low mass (Figure 17). Researchers have shown that individuals who weigh more than the average person are more likely to experience increased discomfort due to cramped and restricted seating conditions (Nadadu & Parkinson, 2009; Vink & Brauer, 2011). Due to the increasing trend of obesity worldwide, it is important for airline companies to consider designing aircraft seats to meet the needs of this population. However, this may lead to an increase in costs.

The effects of seat pan angle and seat height on preferred backrest angle

It was found that seat pan angle and seat height significantly affected the participants preferred backrest angle (Figure 14: The effect of seat pan angle and seat height on participants' preferred backrest angle. Error bars denote 95% confidence interval. Literature states that backrest angles ranging from 100 to 120 degrees decrease spinal disc pressure (Vos *et al.*, 2006). This could explain why the participants preferred backrest angles ranging from about 105 to 115 degrees.

When considering seat height, it was found that the participants preferred a significantly more reclined backrest angle with a low and medium seat height, compared to a high seat height where a more upright backrest angle was preferred. At higher seat heights, it is possible that with a more reclined backrest angle, individuals are more likely to want to stretch out their legs. However with a high seat height, individuals are less likely to be able to stretch their legs whilst keeping their feet in contact with the floor. A more upright backrest angle with a high seat height may result in individuals being able to stretch out their legs to a greater extent whilst their feet remain in contact with the floor.

The effect of sex and seat pan angle on the preferred backrest angle

The only significant difference in preferred backrest angle between males and females was with a 5 degree seat pan angle. At a 5 degree seat pan angle, females were found to prefer a more upright backrest angle compared to males who preferred a more reclined backrest angle (Figure 27: The effect of sex and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval. There are several reasons that could explain these results. Firstly, differences in anthropometry could account for the different preferences in backrest angle. Hiemstra-van Mastrigt (2015) explain how sex is considered an important factor to understand during chair design as the body proportions of males and females vary significantly. Differences in body proportion would result in differences in preferred seating conditions. Park *et al.* (2013) noted that, during a driving simulation experiment, most female drivers preferred a more upright sitting posture compared to their male counterparts. Secondly, these results could also be related to stature. It was previously discussed that taller participants preferred a more reclined backrest angle compared to shorter participants. This could account

for the sex differences, as the female participants were, on average, shorter than the males participants.

The effect of stature and seat pan angle on preferred backrest angle

The effect of seat pan angle on the participants preferred backrest angle was significantly affected by stature (Figure 28: The effect of stature and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval.). At a 5 degree seat pan angle, short participants preferred a more upright backrest angle compared to tall participants who preferred a more reclined backrest angle. It is possible that short participants are able to stretch out their legs to a greater extent when sitting with a more upright backrest angle. Tall participants on the other hand are more likely to feel less cramped and restricted at more reclined backrest angles. No significant difference was found between participants of different statures at a 0 degree seat pan angle.

The effect of stature and seat height on preferred backrest angle

With a low and medium seat height, tall participants preferred a significantly more reclined backrest angle compared to participants of a short and medium stature (Figure 29: The effect of stature and seat height on the participants' preferred backrest angle. Error bars denote 95% confidence interval. Tall participants may have experienced increased restriction and cramped seating conditions at a low seat height with an upright backrest angle. Sitting in a low seat with a more reclined backrest angle may have increased their perceptions of space.

At a high seat height, tall participants preferred an even more reclined backrest angle compared to a low and medium seat height. Referring to earlier observations, taller individuals preferred reclined backrests as this may allow them the opportunity to stretch out, increasing their comfort and their perceptions of increased space. Participants of a short and medium stature considered an even more upright backrest angle to be most comfortable at a high seat height. This result was expected as it was thought that sitting in a high seat would decrease the angle of the backrest the participants considered to be most comfortable.

The effect of body mass and seat pan angle on preferred backrest angle

At a 5 degree seat pan angle, participants with a low mass preferred a more upright backrest angle compared to participants with a medium and high mass (Figure 30: The effect of body mass and seat pan angle on the participants' preferred backrest angle. Error bars denote 95% confidence interval.. Kremser *et al.* (2012) showed that passengers sitting posture is affected by their anthropometry. It is possible that participants with a high mass experienced cramped seating conditions at more upright backrest angles. Upright backrest angles may have also interfered with their large stomachs, resulting in a more reclined backrests being preferred.

The effect of mass and seat height on preferred backrest angle

At a high and medium seat height, participants with a low mass preferred a more upright backrest angle compared to participants with a medium and high mass. At a low seat height there was no difference in preferred backrest angle between participants of different masses (Figure 31: The effect of body mass and seat height on the participants' preferred backrest angle. Error bars denote 95% confidence interval. These results are to be expected as individuals with a greater mass are more likely to experience restricted seating conditions. Therefore a more reclined backrest angle would be more beneficial for them from a comfort perspective.

The effect of BMI and seat height on preferred backrest angle

Participants with a low and high BMI preferred a more reclined backrest angle at low and medium seat heights compared to participants with a medium BMI. At a high seat height, participants with a low and high BMI preferred a more upright backrest angle compared to participants with a medium BMI (Figure 32).

The effects of seat pan angle, seat height and backrest angle on legroom

The amount of space used for legroom by the participants was significantly greater at a 120 degree backrest angle with all seat pan angles and seat heights, compared to the other six backrest angles. The space used was lowest with a 90 degree backrest angle with all seat pan angles and seat heights (Figure 10: The effect of seat pan angle, seat height and backrest angle on legroom. Error bars denote 95% confidence interval. This suggests that the participants preferred to sit with more outstretched legs at greater backrest angles.

It has been stated by Quigley *et al.* (2001) that a decreased seat height potentially increases the amount of legroom required by passengers. The results from this study correspond to this, as the participants used significantly less space for legroom with a high seat height compared to a low seat height. A high seat height limits the opportunity for individuals to change the position of their feet as stretching out the legs too much would mean that the individuals' feet would not be able to touch the floor. It would have been more comfortable for the participants to sit with their feet closer to the seat so that their feet could support their body weight, reducing the pressure placed on the spine and buttocks (Parcells e*t al.*, 1999).

With regards to seat pan angle, the greatest amount of space was used with a 0 degree seat pan angle compared to a 5 degree seat pan angle. There are no known studies on how seat pan angle affects the amount of space individuals' use for legroom. However, the results from this study are not unexpected as tilting the seat pan upwards increases the distance between the floor and the seat pan. This means that the participants were unable to access as much space with a 5 degree seat pan angle as their legs were slightly further away from the floor compared to a 0 degree seat pan angle.

The effect of age and backrest angle on legroom

The participants in the 18-30 year age category used more space than the participants in the 31-60 year age category (Figure 18: The effect of age and backrest angle on the amount of space used for legroom. Error bars denote 95% confidence interval. It is possible that younger participants are likely to sit in a more slouched and spread-out position compared to the older participants.

The effect of body mass and backrest angle on legroom

Participants with a higher mass used more space for legroom compared to participants with a lower mass, particularly at more reclined backrest angles (Figure 19: The effect of body mass and backrest angle on the amount of space used for legroom. Error bars denote 95% confidence interval. Larger participants are more likely to experience cramped and restricted seating conditions (Vink & Brauer, 2011). Therefore, it is likely that participants with a greater mass tried to decrease these feelings of restriction by stretching their legs out.

The effect of BMI and seat pan angle on the space used for legroom

At a 5 degree seat pan angle, participants with a high BMI used a greater amount of space for legroom compared to participants with a low BMI (Figure 20). These results correspond to the effects of mass and backrest angle on space used for legroom. Once again, the participants with a higher BMI were more likely to experience cramped seating conditions. It is likely that these participants would stretch out their legs to a greater extent in order to counteract this.

The effects of seat pan angle, seat height and backrest angle on perceived restriction

At all seat heights, with a 0 degree seat pan angle, the participants' perceived restriction decreased as the backrest was reclined from 90 to 105 degrees, after which it increased again. With a 5 degree seat pan angle, at all seat heights, the participants' perceived restriction increased as the backrest angle reclined from 90 to 100 degrees, after which their perceived restriction increased (Figure 11). It is possible that the increased restriction experienced at a 90 degree backrest angle was due to the participants feeling as though they were leaning forward in their seat, bringing them closer to the backrest of the chair in front of them. A more reclined backrest angle would have increased the participants' perceptions of personal space. From 100 degrees however, it is possible that the participants began to feel that the backrest of the seat in front of them was reclining too far back, once again increasing their perceived restriction.

With regards to seat pan angle, no known research has associated passenger restriction with seat pan angle. However, in this study, it was found that the participants experienced greater feelings of restriction at chest height with a 0 degree seat pan angle compared to a 5 degree seat pan angle. Tilting the seat pan upwards may decrease feelings of restriction as passengers would perceive their seat to be tilted backwards, 'increasing' the distance between them and the seat in front of them. With regards to seat height, no difference in perceived restriction was found at different seat heights.

The effect of stature and backrest angle on perceived restriction

At backrest angles ranging from 90 to 100 degrees, short participants experienced less restriction at chest height compared to participants of a medium and tall stature

(Figure 21). It is possible that taller participants experienced greater restriction at these backrest angles due to being at eye level with the headrest of the aircraft seat in the row in front of them. Therefore, tall participants may have felt closer to the seat in the row in front compared to the shorter participants. It is also possible that the taller participants were forced to lean more forward in their seat due to the headrest. It is likely that shorter individuals were able to rest their head on the headrest, whereas the placement of the headrest for taller individuals was too low, pushing them forward.

From backrest angles of 110 to 120 degrees, the restriction experienced by all participants increased. However, short participants experience a greater increase in restriction compared to participants of a medium and tall stature. It is possible that at greater backrest angles, tall participants experienced less restriction due to being able to stretch out more, as well as being tall enough to see over the backrest of the seat in front of them. Shorter participants probably experienced increases in restriction as the backrest of the seat in front would have obstructed their view.

The effect of lower leg length and backrest angle on perceived restriction

At a 90 and 95 degree backrest angle, participants with a tall lower leg length experienced greater restriction compared to participants with a short and medium lower leg length (Figure 22). It is likely that at these backrest angles, participants with a tall lower leg length experienced increased restriction due to their legs being restricted by the seat in front of them. Although this was a measure of perceived restriction at chest height, it is not possible to ensure that restriction experienced at other areas of the body did not affect the restriction experienced at chest height. From 105 to 120 degrees, the restriction experienced by the participants' increased. However, participants with a short lower leg length experience greater restriction compared to participants with a medium and tall lower leg length. While this finding is unexpected, it is possible that at greater backrest angles, participants with a tall lower leg length experienced greater decreases in restriction due to being able to stretch out their legs. Participants with shorter lower leg lengths may have experienced increases in perceived restriction due to the backrest of the seat in the row in front. These findings suggest that perceived restriction may be affected by different factors for people with different anthropometrics. It seems that for taller

participants, with greater lower leg lengths, perceived restriction is more about how much space is available for legroom, rather than how much space they perceived to have at chest height. This is compared to shorter participants with a shorter lower leg length, whose perceived restriction seems to be more affected by the backrest of the seat in front of them. The space requirements for legroom will be less problematic for shorter individuals compared to taller individuals.

The effects of seat pan angle, seat height and backrest angle on ease of seat access

Seat pan angle, seat height and backrest angle significantly affected the participants' time taken to sit down, as well as the participants' ratings of ease of seat access. At all seat pan angles and seat heights, as the backrest angle reclined from 90 to 120 degrees, the amount of time taken for the participants to sit down increased (Figure 12). These results are consistent with the participants rating of ease of seat access, where ease of seat access was rated as significantly more difficult as the backrest angle reclined from 90 to 120 degrees (Figure 13).

When considering seat pan angle, the time taken for the participants to sit down was significantly faster with a 5 degree seat pan angle compared to a 0 degree seat pan angle. However, seat pan angle had no effect on the participants' rating of ease of seat access. It is possible that the participants took less time to sit down with a 5 degree seat pan angle due to the upward tilt of the seat pan, resulting in less interference with the participants whilst accessing their seat.

Seat height was also found to affect the time taken for the participants to access their seat, but had no effect on the participants' rating of ease of seat access. A high seat height was found to decrease the time taken for the participants to sit down. This result is consistent with previous research which has shown that seat height affects the ease of which individuals are able to sit down and stand up (Janssen *et al.*, 2002). Quigley *et al.* (2001) explains that a seat height that is too low may increase the difficulty of seat access and egress, especially for older or disabled persons. However, the results from this study need to be interpreted with caution as time taken to sit down may have been affected by the platform that the participants were required to step up onto to access their seat. At high seat heights, the participants had a shorter distance to step up onto the platform compared to lower

seat heights, where the platform was raised to decrease the height of the seat. Therefore, with lower seat heights, the participants had to step up further, increasing the time taken for them to sit down. It is possible that if the height of the platform had stayed the same, the time taken to sit down at different seat heights may have produced different results.

The effect of age and seat height on time taken to sit down

At a medium and high seat height, participants in the 18-30 year age category took less time to access their seats compared to participants in the 31-60 year age category (Figure 23). The faster access times of the participants in the 18-30 year age group could be explained by the fact that older individuals experience decreases in strength, agility, reaction times, spatial orientation and mobility (Hertzberg, 1972; McMullin *et al.*, 2014), which may have affected the older participants' ability to step up onto the platform and sit down quickly and efficiently. While these results were expected, it was thought that a low seat height would produce more significant results. Janssen *et al.* (2002) explains how decreasing the height increases the distance over which the individual has to lower their body. This increases the biomechanical demands placed on the body (Janssen *et al.*, 2002). Therefore, it was expected that older participants would have taken longer to access their seat than younger participants. These results could be explained by the experimental set-up whereby an adjustable platform was used to change the height of the aircraft seats, rather than adjusting the seat itself.

The effect of stature and backrest angle on time taken to sit down

While the time taken to sit down increased from a 90 to 120 degree backrest angle, time to sit down was only significantly slower at a 120 degree backrest angle (Figure 24). These results were expected as increasing the angle of the backrest decreases the amount of space available between the two rows of aircraft seats, increasing the difficulty with which the participants were able to access their seat.

The effects of BMI on time taken to sit down

Participants with a high BMI took longer to access their seat compared to participants with a low and medium BMI (Figure 25). This was expected as participants with a greater BMI are subject to increased restriction, making accessing

and egressing the aircraft seat more difficult compared to individuals with a lower BMI.

The effect of lower leg length and seat pan angle on ratings of ease on seat access ratings

At a 5 degree seat pan angle, participants with a short lower leg length rated their ease of seat access as more difficult than participants with a medium and tall lower leg length (Figure 26: The effect of lower leg length and seat pan angle on the participants' rating of ease of seat access {1 = very difficult to access; 5 = very easy to access}. Error bars denote 95% confidence interval.

THE IMPLICATIONS FOR A SOUTH AFRICAN REGIONAL AIRCRAFT

The results obtained from this study are a start to understanding how seating factors affect passenger comfort whilst flying, and can be taken into consideration by Denel with the seat design for SARA. However, there are several factors that need to be taken into consideration when interpreting the results. The methodology used in this study is limiting. Firstly, this was a short-term study, with the participants sitting in the aircraft seat for a minimum of 30 seconds. As a result, all comfort and perceived restriction ratings are a result of immediate impressions. Literature has shown how perceptions whilst sitting change over time (Helander & Zhang, 1997; Fernandez & Poonawala, 1998; Pheasant & Haslegrave, 2006; Cosmi *et al.*, 2008). Therefore, these results are likely to differ if they were to be repeated in a long-term study. This study was also not performed in an aircraft, but in a room in the Human Kinetics and Ergonomics Department. There are several factors that affect comfort, these could include the overhead bins, number of passengers in the aircraft as well as the lighting and colour scheme of the aircraft, to name a few. Lastly, manipulations had to be made, such as the adjustable platform, to change the height of the aircraft seat. This was not an accurate representation of the floor of an aircraft cabin and may have affected the results obtained. These need to be taken into consideration whilst interpreting the results. However, from the results obtained, it can be noted that there are three types of seat design: 1) a seat that provides the most comfort for the passengers, 2) a seat that decreases the space requirements on the aircraft and 3) a compromise between these two seats, whereby adequate passenger comfort is provided, whilst minimising space requirements.

Seat Design for Passenger Comfort

From the results of this study, it is clear that there are certain seating conditions that were perceived by the participants to be more comfortable than others. The participants preferred an aircraft seat with a low and medium seat height, compared to a high seat height. The participants also preferred a 5 degree seat pan angle compared to a 0 degree seat pan angle. If a low and medium seat height, and a 5 degree seat pan angle are considered the most optimal seat factors to increase passenger comfort, then the backrest angle that was most preferred by the participants with a 5 degree seat pan angle and a low and medium seat height is 110 degrees.

Other factors that may affect passenger comfort also need to be considered. These include perceived restriction and ease of seat access. With regards to perceived restriction, the backrest angle that provides the least amount of restriction is a 100/105 degree backrest angle. It was also found that a 5 degree seat pan angle produced decreases in perceived restriction. Generally, it seems that perceived restriction is greatest with a high seat height and is reduced at a low and medium seat height.

Ease of seat access may also impact a passengers' perceived sitting comfort, with seats that are easier to access resulting in increased levels of comfort. From the results obtained, it was found that both time taken to sit down and ratings of ease of seat access increase as the backrest angle is reclined from 90 to 120 degrees. Therefore, the more reclined the backrest angle, the more difficult it is for passengers to access their seat. A 110 degree backrest angle, while increasing the difficulty with which the participants accessed their seat, may not interfere with seat access at a greater seat pitch. Increasing the seat pitch may be an option as a minimum seat pitch of 76cm was used in this study. This did not provide the participants with much space between the row of seats. The results showed that a 5 degree seat pan angle produced easier seat access, as did a high seat height.

Taking all of this into consideration, it can be stated that in order to increase passenger comfort the following seating factors should be used: a low seat height, with a 5 degree seat pan angle and a 110 degree backrest angle.

Seat design for space use

While passenger comfort is important to consider, so is the use of cabin space. From the results, it is clear that there are certain seating factors that would be most appropriate to use if the use of cabin space was the only factor taken into consideration.

With regards to seat height, a high seat height results in a significant decrease in the amount of space used for legroom. A high seat height also results in participants preferring a more upright backrest angle of about 105 degrees. A more upright backrest angle is also associated with decreased space used for legroom, with a 90 degree backrest angle resulting in the least amount of space used for legroom. With regards to seat pan angle, a 5 degree seat pan angle was found to decrease the amount of space the participants used for legroom. It is clear that the more upright the backrest angle, the easier it is for participants to access their seats, with the easiest seat access being at a 90 degree backrest angle. This would mean that the seat pitch would not have to be increased, which would save aircraft cabin space.

In order to save as much space as possible on the aircraft cabin, it would be beneficial to design an aircraft seat with a high seat height, a 5 degree seat pan angle and a 90 degree backrest angle.

Seat design for passenger comfort and space use

Designing a seat to save space and a seat to optimise passenger comfort produces two very different seat designs. However, neither of these two extremes are appropriate, and it would be wise to find a compromise. From the results obtained, it would seem that it is possible to design an aircraft seat that not only increases passenger comfort, but also decreases the amount of space needed for each seat on the aircraft.

With regards to seat height, designing an aircraft seat with a high seat height and a more upright backrest angle would significantly decrease the amount of space needed in the aircraft cabin. However, it would come at a significant cost to passenger comfort. A high seat height with an upright backrest angle may reduce comfort by making the passengers feel as though they are seated too upright and cannot relax. It may also reduce the ability for posture change, particularly with regards to the passenger's feet as the possibility to stretch out the legs would be

reduced due to the height of the seat. Limited ability for posture change has been associated with increased feelings of discomfort and can affect the overall flying experience (Kremser *et al.*, 2012). In order to increase passenger comfort, as well as decrease space needs, it would be beneficial to design an aircraft seat with a medium seat height as this still provides passenger comfort whilst reducing the space needed for legroom. Although seat height was set relative to the participants' lower leg length, it was possible to determine an average low, medium and high seat height. From the participants recruited for this study, the average low, medium and high seat height was 440mm, 480mm and 520mm respectively. This means that a seat height of 480mm would beneficial in terms of increasing comfort whilst minimising the use of space. However, it must be taken into consideration that participants were recruited from Grahamstown only and so is not necessarily representative of the South African population.

With regards to seat pan angle, designing an aircraft seat with a 5 degree seat pan angle was not only found to increase comfort, but was also found to decrease the amount of space used for legroom. Using a 5 degree seat pan angle may contribute to passenger comfort as it was found to reduce feelings of restriction at chest height, as well as increase passenger ease of seat access (Dumur *et al.*, 2004). Due to the economic effects of boarding time, decreasing the time taken for passengers to access their seat would result in reduced costs for the airline company. Easy seat egress is also important in an emergency situation where a few seconds less to egress the aircraft seat could increase the pace and efficiency with which the passengers are able to vacate the aircraft (Tan *et al.*, 2009).

When considering space needs with regards to backrest angle, it should be noted that backrest angles at both a 0 and a 5 degree seat pan angle should result in the same amount of space needs. For example: a 100 degree backrest angle with a 0 degree seat pan angle should have the same space requirements as a 105 degree backrest angle with a 5 degree seat pan angle. From the results, it was found that at a 5 degree seat pan angle, a backrest angle of 110 degrees resulted in the greatest comfort, compared to a 115 degree backrest angle with a 0 degree seat pan angle. Therefore, it would be better to use a 5 degree seat pan angle with a 110 degree backrest angle as this would not only increase passenger comfort, but would also save cabin space. It should also be noted that the amount of space used for legroom

is not significantly greater at a 110 degree backrest angle compared to other backrest angles. Although a backrest angle of 110 degrees increases the participants perceived restriction, as well as the time taken to sit down, this could be improved by increasing the seat pitch to an appropriate distance. However, this would come at a cost to cabin space.

From the results, it can therefore be stated that to design an aircraft seat that optimises passenger sitting comfort, whilst reducing space needs, a medium seat height, with a 5 degree seat pan angle and a 105/110 degree backrest angle should be used.

CHAPTER VI
SUMMARY, CONCLUSION AND RECOMMENDATIONS

INTRODUCTION

Sitting discomfort in aircraft seats is a common cause of complaint whilst flying. Due to the highly competitive nature of the aviation industry, it is important for airline companies to attract and retain customers. One of the main ways in which to do this is through meeting customer requirements, such as passenger comfort whilst flying. However, it is not only passenger comfort that needs to be considered, but also the use of cabin space. Increasing revenue is often achieved through increasing the number of passengers that can fly at one time. Increasing the number of passengers can be achieved through limiting the amount of space available for each aircraft seat. This, however, leads to passenger discomfort. It is therefore important to find a balance between passenger comfort and the use of cabin space. This can potentially be done through the manipulation of different seating factors, such as seat pan angle, seat height and backrest angle.

SUMMARY OF PROCEDURES

The current research examined how seat pan angle and seat height affected the preferred angle of the backrest, as well as how seat pan angle, seat height and backrest angle affected participant comfort, ease of seat access, perceived restriction and space used for legroom. For this study, a total of 80 participants were recruited, consisting of 40 males and 40 females. The participants were split into two age groups, 18-30 years of age and 31-60 years of age. The participants' average stature, body mass, BMI and lower leg length was 170.66cm, 76.10kg, 26.01kg/m^2 and 51.8cm respectively.

This study consisted of two parts. The first part required the participants to sit in 42 seating conditions, consisting of a 0 and 5 degree seat pan angle, a low, medium and high seat height, as well as 7 backrest angles ranging from 90 to 120 degrees. For each seating condition, the time taken for the participants to access their seat was recorded. The participants rated their ease of seat access, how restricted they felt at chest height and gave a comparative comfort rating. The comparative comfort rating consisted of comparing the comfort of the current seating condition to the comfort of the previous seating condition. The amount of space the participants used

for legroom was measured. After the rating of the 42 seating conditions, it was possible to determine which backrest angle was preferred for each seat pan angle and seat height. This resulted in the second part of the study which consisted of 6 seating conditions. During this part of the study, the participants were required to rate the comfort of these 6 seating conditions on an absolute rating scale.

SUMMARY OF RESULTS

From the results obtained, it was found that seat pan angle, seat height and backrest angle did affect the participants perceived comfort, ease of seat access, perceived restriction and legroom. It was also found that seat pan angle and seat height affected the preferred angle of the backrest. From this study, it is clear that certain seating factors are preferred by the participants in terms of comfort, whilst other seating factors are more beneficial for saving aircraft cabin space.

The results from this study showed that seat pan angle, seat height and backrest angle do have an effect on seat design and that these factors should be taken into consideration. From the results, it was found that, from a comfort perspective, seat pan angle, seat height and backrest angle all affected the participants' perceived sitting comfort. For example, at all seat heights, sitting comfort increased as the backrest was reclined from 90 to 110/115 degrees, after which comfort ratings decreased. While the trend was the same for all seat heights, it was found that, a low seat height produced greater comfort ratings compared to a high seat height, as did a 5 degree seat pan angle compared to a 0 degree seat pan angle. Seat pan angle, seat height and backrest angle not only affected comfort, but also affected ease of seat access and perceived restriction. Ease of seat access times were faster with a 5 degree seat pan angle and a high seat height. As the backrest angle was reclined from 90 to 120 degrees, the participants' access times increased, suggesting that seat access is easier with a more upright backrest angle. These results are consisted with the participants' rating of ease of seat access. Participants rated their ease of seat access as easier with a 5 degree seat pan angle and more upright backrest angles. There was no difference in ease of seat access ratings between different seat heights.

The results also showed that seat pan angle, seat height and backrest angle had an effect on seat design when it comes to space use. For example, a 5 degree seat pan

angle, a high seat height and a more upright backrest angle all results in less space used for legroom, which would decrease the amount of space needed for each aircraft seat.

Seat design for passenger comfort

The results from this study showed that the different seating conditions resulted in significantly different comfort ratings. It was found that a low seat height produced the highest comfort ratings compared to a medium and high seat height. With a 0 degree seat pan angle, the participants preferred a backrest angle of 110/115 degrees. With a 5 degree seat pan angle, the participants preferred a backrest angle of 105 degrees. However, aircraft seats with a 5 degree seat pan angle received significantly greater comfort ratings compared to a 0 degree seat pan angle. Therefore, to design a seat for passenger comfort, an aircraft seat should consist of a low seat height, with a 5 degree seat pan angle and a 105 degree backrest angle.

Whilst the design of the aircraft seat plays a role in passenger comfort, so do other factors, such as perceived restriction and ease of seat access. This study revealed that the participants experienced less restriction at chest height with a low and medium seat height, backrest angles of about 100/105 degrees, as well as a 5 degree seat pan angle. It is possible that the reduced restriction at chest height experienced at these seating conditions contributed to the comfort of the participants. This study also revealed that seat access was easiest at a high seat height and a 5 degree seat pan angle. Seat access became significantly more difficult as the backrest angle was reclined from 90 to 120 degrees. Ease of seat access however did not seem to affect the participants comfort ratings. While seat access was rated as extremely difficult at backrest angles ranging from 110 to 120 degrees, this may have been as a result of the seat pitch. A greater seat pitch may have reduced the difficulty with which the participants were able to access their seats.

Seat design for space use

While designing aircraft seats for passenger comfort is important, it is also necessary to design for the efficient use of cabin space. The results from this study revealed that to use the least amount of cabin space, the aircraft seat needs to have a high seat height, a 5 degree seat pan angle and a 90 degree backrest angle. These

seating factors resulted in the participants using the least amount of space for legroom. A 90 degree backrest angle would also allow for the easiest seat access, which would mean that the seat pitch would not have to be increased, which would save space on the aircraft.

Designing an aircraft seat with the intent to either save cabin space, or optimise passenger comfort, results in two extremes. This is not an option and a compromise needs to be made. From the results, it seems possible to design an aircraft seat that not only reduces space needs but also allows for passenger comfort. An aircraft seat designed to find a compromise would likely consist of a medium seat height, as this provides passenger comfort, but also reduces the amount of space used for legroom to a certain extent. Using a 5 degree seat pan angle also allows for passenger comfort whilst reducing space used for legroom. A backrest angle of about 105/110 degrees results in passenger comfort and does not significantly increase the amount of space used for legroom. Whilst this backrest angle may increase the difficulty with which passengers are able to access their seats, it would be possible to counteract this by increasing the seat pitch.

RESPONSE TO HYPOTHESIS

1. H_A: μ(Bra90) ≠ μ(Bra95) ≠ μ(Bra100) ≠ μ(Bra105) ≠ μ(Bra110) ≠ μ(Bra115) ≠ μ(Bra120)

The alternate hypothesis was accepted as backrest angle did affect the participants perceived subjective discomfort, ease of seat access, perceived restriction and legroom at all seat pan angles and seat heights.

2. H_A: μ(0spa)(Lsh)(90-120bra) ≠ μ(0spa)(Msh)(90-120bra) ≠ μ(0spa)(Hsh)(90-120bra) ≠ μ(5spa)(Lsh)(90-120bra) ≠ μ(5spa)(Msh)(90-120bra) ≠ μ(5spa)(Hsh)(90-120bra)

The alternate hypothesis was accepted as seat pan angle and seat height, at the preferred backrest angle, did affect the participants' perceived subjective comfort.

RELIABILITY OF THE DATA

Some of the methods and techniques of measuring the effects of seating conditions on ease of seat access, perceived comfort, perceived restriction and space used for legroom, were adopted from previous studies. However, some of the measuring techniques had to be created so as to be able to test the research hypothesis, such as the comparative rating of comfort. In order to increase the reliability of the data, there are certain aspects within the methodology that could be changed or improved. This experiment was conducted in a laboratory setting, and although aircraft seats were used, these were not the seats that will be used in SARA. Testing in an aircraft would have been beneficial as it is likely that the testing venue may have affected the results obtained.

Due to the number of conditions, this study was a short-term investigation, with the participants remaining seated in each seating condition for a minimum of 30 seconds. It is known that real sitting discomfort only sets in after a longer period of time. Allowing the participants to sit for a longer period of time would have been more beneficial and more accurate results may have been obtained. However, due to the number of seating conditions, this was not possible.

Although factors such as seat pan angle, seat height, backrest angle and seat pitch were controlled for, it was not possible to control for other factors such as seat width. This was problematic as it is possible that seat width may have affected factors such as ease of seat access, perceived restriction as well as sitting comfort. Unfortunately it was not possible to control for this as there was no way of altering seat width. Investigating the role of seat width would have also increased the number of seating conditions.

The seat height was controlled for by developing an adjustable platform, which acted as the floor, in order to change the height of the aircraft seat. While this allowed for easy adjustment of seat height during the testing process, it was not an accurate set-up of a cabin interior. It meant that the participants had to step-up onto a platform that was not as stable as a cabin floor would be. This may have affected factors such as time to sit down and ratings of ease of seat access.

Methods and techniques of measurement may have affected the results. BMI was determined using the standardised formula of mass/height^2. Skinfolds and Bioelectrical Impedance Analysis (BIA) could have been used to measure body composition, however, this would have resulted in a longer testing duration.

The use of objective measures, alongside subjective measures, would have been beneficial to further increase the reliability and validity of the results. However, due to the nature of the testing procedure, this was not possible. Determining ratings of sitting comfort and perceived restriction were only possible through subjective rating scales. Objective measures only become useful during long-term sitting when muscle stiffness and pain, as well as lower limb oedema may occur.

Improved measuring techniques and methods could have been used in this study. However, the methods used were selected due to a number of reasons such as data collection and time restraints, as well as equipment constraints which limited the ability to alter the aircraft seats in the desired manner.

CONCLUSION

The current study reveals that aircraft seating factors, such as seat pan angle, seat height and backrest angle affect passenger sitting comfort, ease of seat access, perceived restriction and legroom. It was revealed that seat pan angle and seat height affect which backrest angle was preferred by the participants. This study also revealed that individual characteristics such as age, sex, stature, mass, BMI and lower leg length affected the dependent variables.

The data obtained indicates that aircraft seat design is a complicated process and needs to be understood if passenger comfort is to be increased whilst optimising the use of cabin space. These results are beneficial as they may act as a guideline for Denel to make a decision on the seat dimensions that will be used in SARA.

RECOMMENDATIONS FOR FUTURE STUDIES

While this study sheds light on the interaction between seating characteristics and their effects on passengers, there are several things that could be improved on in studies going forward. It would be highly beneficial to perform testing in an aircraft cabin. Testing in an aircraft cabin would mean that other factors would come into play that may affect passenger comfort, such as the overhead bins, increased

number of seats, windows and lighting to name a few. Testing in an aircraft cabin would also mean that the floor of the fuselage would be set to 3 degrees with respect to the horizontal. This is something Denel should take into account as it will likely affect the seat design.

With regards to seat height, it would have been beneficial to have designed the aircraft seats so that the height of the seat could have been easily adjusted, without the use of a platform. Future studies should also consider using a set seat height as setting seat height relative to the participants lower leg length does not allow for a set seat height to be recommended. However, for this study, having a relative seat height was necessary to understand the interaction between seat height, seat pan angle and backrest angle. This was the first step to understanding passenger sitting comfort. From here, further studies can look at what the recommended seat height should be for the African population.

Much of the literature states that comfort and discomfort should be rated on two separate scales (Helander & Zhang, 1971; de Looze *et al.*, 2003), as comfort and discomfort are two separate phenomenon. However, due to the nature of this study, comfort and discomfort had to be rated on one scale. Due to the number of conditions, the participants used a comparative rating scale to compare the comfort of the 42 seating conditions. Separating comfort and discomfort into two rating scales would have made comparting the seating conditions difficult for the participants and it is likely that the participants would have started giving random (dis)comfort values as it would have been easy for them to forget the (dis)comfort of the first few seating conditions. It would have also complicated the analysis of the results. The absolute rating of comfort was also on a single scale as this was a short term test and so measure of (dis)comfort were immediate impressions. It is likely that for long term sitting, the distinction between comfort and discomfort would become more apparent, and so having two different rating scales would be more appropriate. This would be worth taking into consideration for a follow-up study.

Further recommendations for future studies would include long-term testing of sitting comfort. It is possible that different seating conditions will affect passengers differently over prolonged periods of time, particularly without the opportunity for posture change. Included in this, would be how different activities affect passenger

comfort whilst sitting. Aesthetics is also known to play a role in sitting comfort. It would be interesting to assess how the design of the aircraft seat, as well as the cabin interior affects passengers' sitting comfort. Lastly, it would be highly beneficial to investigate how factors such as comfort are affected by performing other activities, such as working on a laptop, reading a book, watching a movie, eating or sleeping.

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APPENDICES

APPENDIX A: PARTICIPANT INFORMATION

Appendix A1: Letter of Information

Dear Participant,

I am conducting a study which consists of two parts. The first part of this study is to investigate whether seat pan angle, seat height and backrest angle affects perceived comfort, ease of seat access, perceived restriction and legroom, as well as preferred backrest angle. The second part of this study aims to determine how seat pan angle and seat height, with the preferred seat height affects sitting comfort. I am investigating this as passengers continue to complain about a lack of comfort whilst sitting in aircraft seats due to cramped and restricted seating conditions. These complaints manifest in the forms of aches and pains, stiffness and swelling of the lower limbs. Therefore, it is important to investigate how this discomfort can be reduced to improve the flying experience. However, the use of available cabin space also needs to be considered to determine how space can be optimized to reduce costs.

The first part of this test requires you to rank a total of 42 aircraft seating conditions according to how comfortable you perceive them to be. Each seat that you sit in will consist of a different height, seat pan angle and backrest angle. The total duration of this procedure will be about 1 hour and 30mins. At the beginning of this test your weight and height will be recorded. You will also have your lower leg length measured to determine the seating parameters. Once the seat has been adjusted accordingly, you will be required to move to your seat. The amount of time that it takes you to sit down will be measured. Once you are seated you will rate your ease of seat access. Once seated you may sit however you want but you will not be allowed to get up. You will be required to rate your how restricted you feel at chest height. The amount of legroom you use will also be measured. You will then be required to sit in the seat for a minimum of 30 seconds before you can rate your

comfort. Once you have rated your comfort, you will be asked to get up from your seat and walk around as desired whilst the seat is readjusted. The same procedure as above will then take place. This will be done for all 42 conditions.

Once you have completed the 42 seating conditions, you will be required to rate a further 6 seating conditions. These will consist of the most preferred backrest angle for each seat pan angle and seat height.

Please note that this is a voluntary procedure and should you feel distressed and do not wish to continue, you may withdraw from testing at any given time without any adverse consequences.

There are a certain number of risks associated with this study, however these are minimal. During this test you may feel a certain degree of boredom and fatigue as you will be rating the comfort of many seating conditions. However testing should not last longer than 1hour 30mins. You will also be given the opportunity to walk around and stretch between conditions while the chairs are being adjusted. While you may experience some degree of discomfort, this risk has been minimized by ensuring that you only have to sit in each seating condition for 30 seconds. Therefore the discomfort experienced will be minimal.

Personal benefits to you will mostly be educational in nature. It will provide you with the opportunity to gain a better understanding of sitting comfort and how it is affected by different seating conditions. Participating in this study will allow you insight into what research is being conducted in the HKE department. This study will also contribute to the greater community at large as it shall provide insight into how different aircraft seating conditions affect perceptions of discomfort as well as the use of cabin space on aircrafts.

The data that will be collected will be stored until the thesis is completed. However, your anonymity will be protected as each participant will be given codes. Photographs will be taken for illustrative and data collection purposes but only if permission has been granted from you. Your anonymity will be protected by blocking out your face if the photographs are used.

Thank you for your time and co-operation.

Emma-Jane Olley

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G4o0487@campus.ru.ac.za

Appendix A2: Letter of Informed Consent

I, _____, have been fully informed of the research project entitled: "THE EFFECT OF DIFFERENT SEATING CONDITIONS, IN AIRCRAFTS, ON PASSENGER COMFORT AND THE USE OF CABIN SPACE". I hereby give my consent to be a participant in the above named research.

I am fully aware of all procedures, risks and benefits that are involved with partaking in this study. These have been explained to me both verbally and in writing. By agreeing to participate in this study I accept joint responsibility together with the Human Kinetics and Ergonomics Department in that should any accident or injury occur as a direct result of the protocol being performed during the study, the Human Kinetics and Ergonomics department will be liable for costs which may ensue and will reimburse the participant to the full amount. This includes doctors' consultation, medication and rehabilitation etc. The Department however will not waiver any legal recourse against the researcher or Rhodes University in the event the injury is self-inflicted due to negligence on the part of the participant, or is in any other way not related directly to the study itself.

I have been informed that my picture may be taken. I understand that this is for the purpose of data collection and that my anonymity will be protected at all times.

I understand that if, at any point, I express any concerns, or distress about my participation in this study, I must express these to the researcher immediately. I am aware that I may withdraw from this study at any point without any adverse consequences. I am also aware that my anonymity will be protected at all times, and I agree that all the information collected may be used and published for statistical and scientific purposes.

I have read the information sheet accompanying this form and understand all procedures. Any questions that have occurred to me have been answered to my satisfaction.

Participant:	_____	_____	_____
(Print name)	(Sign)	(Date)	
Researcher:	_____	_____	_____
(Print name)	(Sign)	(Date)	
Witness:	_____	_____	_____
(Print name)	(Sign)	(Date)	

APPENDIX B: RATING SCALES

Appendix B1: Comparative Rating of Comfort

-2	Significantly less comfortable than previous seating condition
-1	Slightly less comfortable than previous seating condition
0	No difference in comfort
+1	Slightly more comfortable than previous seating condition
+2	Significantly more comfortable than previous seating condition

Appendix B2: Absolute Rating of Comfort

0	Maximum discomfort
1	
2	Significant discomfort
3	
4	Slight discomfort
5	No perceived comfort or discomfort
6	Slight comfort
7	
8	Significant comfort
9	
10	Maximum comfort

Appendix B3: Ease of Access Rating Scale

1	Very easy to access
2	Easy to access
3	Neutral
4	Difficult to access
5	Very difficult to access

Appendix B1: Perceived Comfort Rating Scale

1	Significant restriction
2	
3	Neutral
4	
5	Not at all restricted

APPENDIX C: CONVERTING RELATIVE COMFORT TO ABSOLUTE COMFORT

Table 21: The absolute comfort rating for the most preferred backrest angle for each seat height at a 0 degree seat pan angle

Participant 1	Seat Pan Angle (0 degrees)	
	Low seat height	
	Backrest angle	Comfort rating
	(A1) 120	(B1) 9

Table 22: The conversion from relative comfort to absolute comfort for a low seat height with a 0 degree seat pan angle

Seating condition	L090	L095	L0100	L0105	L0110	L0115	L0120
Relative comfort (-2 to+2)	(A2) 0	(B2) 1	(C2) 2	(D2) 2	(E2) 3	(F2) 4	(G2) 5
Angle (degrees)	(A3) 90	(B3) 95	(C3) 100	(D3) 105	(E3) 110	(F3) 115	(G3) 120
Dif-Ref	(A4) =IF($A1=A3,$B1-A2,0) [0]	(B4) =IF($A1=B3,$B1-B2,0) [0]	(C4) =IF($A1=C3,$C1-C2,0) [0]	(D4) =IF($A1=D3,$B1-D2,0) [0]	(E4) =IF($A1=E3,$B1-E2,0) [0]	(F4) =IF($A1=F3,$B1-F2,0) [0]	(G4) =IF($A1=G3,$B1-G2,0) [4]
Difference	(A5) =SUM(A4:G4) [4]	(B5) =A5 [4]	(C5) =B5 [4]	(D5) =C5 [4]	(E5) =D5 [4]	(F5) =E5 [4]	(G5) =F5 [4]
Absolute	(A6) =A6:AG6=A2+A5 [0]	(B6) =B2+B5 [5]	(C6) =C2+C5 [6]	(D6) =D2+D5 [6]	(E6) =E2+E5 [7]	(F6) =F2+F5 [8]	(G6) =G2+G5 [9]

Table 21 shows the absolute comfort rating (0-10) given by one participant for their most preferred backrest angle at a low seat height with a 0 degree seat pan angle.

Table 22 displays the seating conditions for a low seat height, with a 0 degree seat pan angle and backrest angles ranging from 90-120 degrees. Only a low seat height with a 0 degree seat pan angle has been displayed as the formulas stay the same throughout and this was necessary to avoid repetition. The letter and number in brackets of each cell represents the cell 'code'-this is necessary to be able to establish which cell is being referred to in the formulae. The numbers in square brackets refer to the values obtained from the formulas.