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Predicting passenger seat comfort and discomfort on the basis of human, context and seat characteristics: a literature review

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ABSTRACT
This literature review focused on passenger seat comfort and discomfort in a human–product–context interaction. The relationships between anthropometric variables (human level), activities (context level), seat characteristics (product level) and the perception of comfort and discomfort were studied through mediating variables, such as body posture, movement and interface pressure. It is concluded that there are correlations between anthropometric variables and interface pressure variables, and that this relationship is affected by body posture. The results of studies on the correlation between pressure variables and passenger comfort and discomfort are not in line with each other. Only associations were found between the other variables (e.g. activities and seat characteristics). A conceptual model illustrates the results of the review, but relationships could not be quantified due to a lack of statistical evidence and large differences in research set-ups between the reviewed papers.

Practitioner Summary: This literature review set out to quantify the relationships between human, context and seat characteristics, and comfort and discomfort experience of passenger seats, in order to build a predictive model that can support seat designers and purchasers to make informed decisions. However, statistical evidence is lacking from existing literature.

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KEYWORDS
Sitting comfort; body posture; anthropometry; pressure distribution; seat design

1. Introduction

Numbers of passenger transport are increasing. For example, in 2013, over 3 billion passengers were carried by the world's airlines (ATAG 2014), and numbers are growing. According to the global market forecast by Airbus, air traffic will double in the next 15 years, showing 4.7% annual growth between 2013 and 2033 (Airbus 2014). Air traffic has proven to be resilient to external shocks, as it has shown 73% growth through multiple crises over the last 10 years (e.g. SARS, financial crisis). Similarly, the sales volume of automobiles shows continuous growth. For example, car sales volumes of the BMW Group almost doubled the past five years, delivering almost two million vehicles in 2014.

Next to an increase in the number of air passengers, there is also an increase in the diversity of air passengers. Air transport growth is highest in emerging regions such as India, Africa and Eastern Europe. For example, the expected 20-year growth is largest for the Middle East (7.1% a year) and Asia-Pacific (5.7%). The growth in emerging regions can also be seen for the automotive industry. Although it is expected to slow down to an average of 8% a year between 2011 and 2020, China's automotive sector grew at an average rate of 24% a year between 2005 and 2011 (Wang, Liao, and Hein 2012). Hence, also in the automotive industry, the diversity in drivers and passengers is increasing. The same development is seen for train passengers. Trains are becoming a competitive alternative for air travel as a result of innovations in railway. Compared to short and medium distance flights, train journeys could be faster, in particular for high-speed lines covering distances up to 800 km (European High Speed Rail – An Easy Way to Connect 2009). While trains have traditionally transported passengers more or less in the same area, the diversity of train passengers will increase as well due to longer distances covered by high-speed lines.

Furthermore, a revolution in information technology devices, applications and networks introduces a larger variation in activities that passengers can perform while travelling. It is expected that the use of small handheld devices, such as PDAs, smart phones, e-readers and tablet PCs, will continue to increase, thereby increasing the number of passengers that is using these devices. These modern technologies and the shift towards a service- and

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knowledge-driven economy allow people to work while travelling. In London, 20% of commuters spend more than two hours a day travelling to and from work, adding up to one working day a week (Transport for London 2009). Supported by these new technologies, knowledge workers are able to work anywhere, at any time, thus allowing passengers to use their travel time for work activities. Results from a survey performed in the USA in 2008, for example, show that 21% of respondents conducted work activities while on an airplane, train or subway (WorldatWork 2009).

Comfortable seats can attract passengers (Vink et al. 2012). To attract passengers, seats should take into account this increasing cultural diversity of passengers and the activities that they want to perform during travel. Passenger seats should allow people to feel fit after a few hours travelling without experiencing discomfort. However, little is known yet about the influence of passengers' anthropometry, the activities they perform and the properties of the seat, on the comfort and discomfort perception of passengers. Also, it is unclear how this knowledge can be incorporated into the design process of seats. Until now, these aspects concerning sitting comfort and/or discomfort have only been considered in separate studies, and little is known about their interdependencies and interactions, let alone their effect on comfort and discomfort. Hence, the exact (quantified) relationships between human, seat and context characteristics remain unclear.

According to Zhang, Helander, and Drury (1996), comfort and discomfort are two independent factors associated with different underlying factors. Discomfort is associated with feelings of pain, soreness, numbness and stiffness, and is caused by physical constraints in the design. Comfort, on the other hand, is associated with feelings of relaxation and well-being, and can be influenced by, for example, the aesthetic impression of a product or environment. Thus, reducing the level of experienced discomfort will not necessarily increase the level of comfort, but in order to accomplish a high level of comfort, the level of discomfort needs to be low (Helander and Zhang 1997).

Building upon the model by Helander and Zhang (1997), the theoretical model of comfort and discomfort and its underlying factors by De Looze, Kuijt-Evers, and Van Dieën (2003) distinguishes three levels: human, seat and context levels (see Figure 1). For instance, at context level, the physical environment has an influence on sitting discomfort, whereas at seat level, aesthetic design can also influence sitting comfort. Although the models of Helander and Zhang (1997) and De Looze, Kuijt-Evers, and Van Dieën (2003) contribute to the understanding of the concepts 'comfort' and 'discomfort', none of these is able to predict either comfort or discomfort.

Therefore, the aim of this study is to investigate whether it is possible to predict passenger seat comfort and discomfort on the basis of human, context and seat characteristics. Ideally, the results of this study could be applied in future studies to build a predictive model that can be used to indicate perceived comfort and discomfort based on human, contextual and seat characteristics. Since this study aims to quantify these relationships, the focus is on measurable,

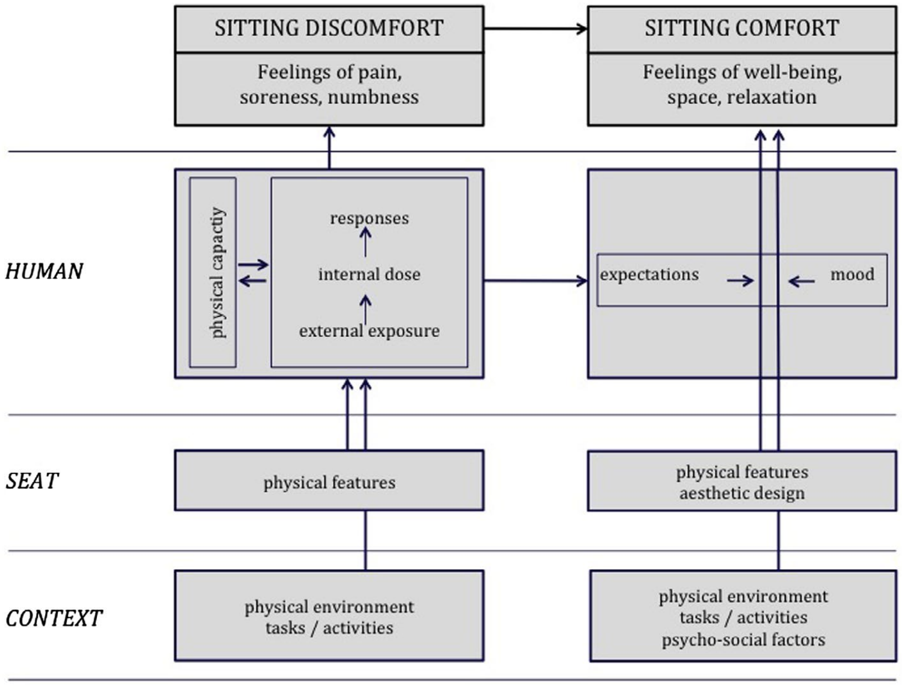

Figure 1. Theoretical model of sitting comfort and discomfort and its underlying factors at the human, seat and context levels (redrawn from De Looze, Kuijt-Evers, and Van Dieën 2003).

physical elements. That is why, for this study, anthropometric dimensions have been selected to describe the human characteristics. Performed activities are considered the most important context characteristics. Seat characteristics are described as physical features of the seat, such as dimensions, shape and material (hardness). A conceptual model has been constructed to serve as a basis for the literature review, by visualising how human, seat and context characteristics are influencing passenger seat comfort (see Section 2.1).

2. Methods

2.1. Conceptual model

A conceptual model illustrating the hypotheses on the relationships between the variables that affect comfort and discomfort has been constructed, using the model of sitting comfort and discomfort developed by De Looze, Kuijt-Evers, and Van Dieën (2003) as a starting point. The model of De Looze, Kuijt-Evers, and Van Dieën (2003) is based on the interaction between the seat and the human within a certain context (see Figure 1). Their model is based on the theory of Helander and Zhang (1997), who consider discomfort and comfort as two separate entities, with discomfort having a dominant effect. The new conceptual model building upon these two models is shown in Figure 2.

The underlying factors of sitting comfort and discomfort exist on the human, seat and context levels (De Looze, Kuijt-Evers, and Van Dieën 2003). The left part of the new conceptual model in Figure 2 illustrates these three levels in separate boxes. Together, the combination of these human, seat and context characteristics determines a passenger's sitting posture, associated interface pressures (contact between human body and seat surface) and movements, illustrated in the middle. On the right, the outcome is shown as separate levels of perceived comfort and discomfort. The dashed arrow from discomfort towards comfort indicates the dominant effect of discomfort.

Hence, the relationship between human, seat and context characteristics (left) and the perception of comfort and discomfort (right) can be explained by three mediating variables: posture, pressure and movement (middle). For example, body posture is not only determined by a passenger's anthropometry (human), but also by the seat characteristics (e.g. reclined backrest angle) and context (the performed activity, such as reading or working on laptop).

Using the new conceptual model as a framework, three research questions have been formulated in more detail. The following relationships will be investigated (numbers correspond with subsections in this paper):

3.1. The effects of human, seat and context characteristics on mediating variables
    3.1.1. Human characteristics (anthropometry of passengers)
    3.1.2. Seat characteristics (shape, dimensions and material)
    3.1.3. Context characteristics (activities of passengers)
3.2. The interdependencies between the mediating variables
    3.2.1. Interface pressure and sitting posture
    3.2.2. Interface pressure and movement
3.3. The effects of mediating variables on the perception of comfort and discomfort

2.2. Literature review

This literature review focused on the relationships between anthropometrics (human level), seat characteristics (seat level) and the activities of passengers (context level), on perception of comfort and discomfort, and how this is

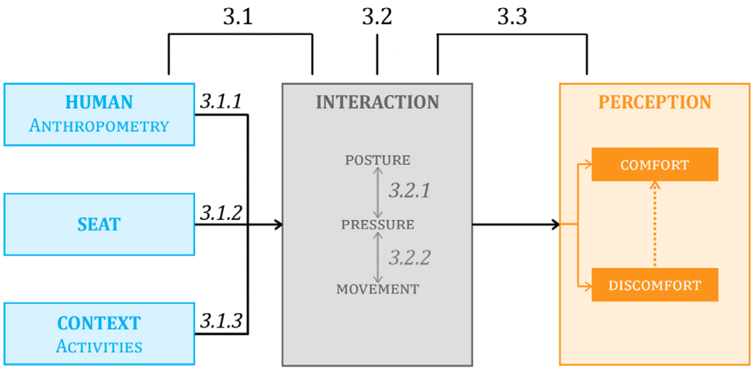

Figure 2. New conceptual model used as framework for literature review (numbers referring to subsections in this paper). The effect of human, seat and context characteristics (left) on the perception of comfort and discomfort (right) is influenced by mediating variables: sitting posture, interface pressure and movement (middle).

influenced by three mediating variables: sitting posture, interface pressure and movement. The studies for the literature review were retrieved through a search in Scopus. The following combination of terms were searched for in article title, key words and abstract (exact search words in brackets): **human** ('anthropometrics', 'weight', 'height' or 'BMI'), **seat** ('cushion' or 'material') and **context** ('activity', 'activities' or 'task') characteristics on **comfort and discomfort** ('sitting comfort', 'sitting discomfort' or 'passenger comfort'), influenced by **posture**, **pressure** ('pressure distribution', 'pressure', 'maximum pressure' or 'pressure gradient') and/or **movement.** In addition, relevant references from the selected articles were checked. Articles were included in this review only if they met all three of the following criteria:

1. The paper describes an experiment or a literature review related to comfort and/or discomfort measurements in sitting/while seated in combination with measurements of anthropometry and/or pressure measurements.
2. The paper describes a study with healthy subjects in standard sitting situations; i.e. studies regarding decubitus or with a focus on sitting in wheelchairs are excluded.
3. The paper is available and published in English and published after 2003 (except for reviews and high-impact (>50 citations and/or high-quality journal) papers).

3. Results

From the Scopus search results, 90 studies were selected for full-text reading after reading their abstracts. From this selection, 32 studies met the inclusion criteria. After checking relevant references, an additional 13 studies were included. All of these studies describe an experiment in which sitting discomfort and/or sitting comfort, human and/or context and/or seat and/or one of the mediating variables (posture, interface pressure movement) were measured. In 11 studies, correlations were calculated between some or all of the variables. Almost none of the studies reported effect sizes.

The conceptual model presented in Figure 2 is the framework in which the findings from the literature are presented in this paper. Human, seat and context characteristics and their influence on the mediating variables (posture, movement and interface pressure) are described first (Section 3.1). Then, the interdependencies between the mediating variables posture, movement and interface pressure are described (3.2). Finally, the relationships between the mediating variables (posture, movement and interface pressure) and comfort and discomfort are described (3.3).

3.1. Effects of human, seat and context characteristics on mediating variables

3.1.1. Human characteristics and their effects on mediating variables

In this paper, human characteristics have been limited to anthropometric variables, such as stature, weight, somatotype and body mass index (BMI) or reciprocal ponderal index (RPI). This section describes the associations between anthropometry and the mediating variables: posture, movement and interface pressure.

3.1.1.1. Effects of anthropometry on posture and movement. Only a few studies report about *body postures* in relation to *anthropometric* variables in the context of seating. After observing train passengers, Branton and Grayson (1967) were the first to report that tall people sat in postures with knees crossed for longer periods than short people, particularly when slumped. Compared to the tall people, the short people sat more often with both feet on the floor. In research about home furniture, Teraoka, Mitsuya, and Noro (1994) also found differences between tall and short people: in comparison with tall people, short people had less foot contact with the floor, or less contact with the backrest in combination with a slumped posture. Ciaccia and Sznelwar (2012) concluded that the participants in their study adopted very similar postures for both reading and resting in order to avoid discomfort, despite having different anthropometric characteristics. However, this was based on an observational study with only five participants (Ciaccia and Sznelwar 2012). In a driving simulation experiment, Park et al. (2013) found a relationship between upper body posture and gender; most of the female drivers preferred a slouched or erect posture, while most of the male drivers preferred a slouched or reclined posture. In a study on car driver seats, Kyung and Nussbaum (2013) found that older drivers preferred a higher and more upright driving posture (SUV seat configuration), while younger drivers preferred a more reclined posture (sedan seat configuration).

In summary, five studies reported that different body postures were associated with anthropometric characteristics (stature, gender and age). No studies were found in which correlations were reported between anthropometry and movement.

3.1.1.2. Effects of anthropometry on interface pressure. Six studies reported a correlation between *anthropometry* and *pressure*. Different variables of pressure were studied, such as contact area, sitting force, mean pressure, peak pressure, pressure factor (the combination of peak and mean pressure) and pressure gradient. Anthropometric variables were stature, weight, gender, age, BMI, RPI, percentage of subcutaneous fat and ectomorphic index. Below, the correlations are described for each pressure variable. Table 1 provides an overview of these correlations.

Six studies found effects of anthropometric variables on *contact area*. For vehicle occupant seats, Paul, Daniell, and Fraysse (2012) found a correlation between weight and contact area on the seat pan (r ranges from $r = 0.432$ to $r = 0.845$), and between weight and contact area on the backrest ($r = 0.432$ to $r = 0.741$) for different car seats. Differences between car seats were explained by different body postures. According to Paul, Daniell, and Fraysse (2012), body mass and hip circumference were the best anthropometric indicators for the seat pan contact area. Kyung and Nussbaum (2008) also found effects of stature on pressure variables related to the contact area in the driver's seat of cars. The contact area at the right thigh (due to the asymmetric driving posture) and that at the upper back was significantly larger for taller persons. Vos et al. (2006) found correlations between several anthropometric variables and the seat pan contact area in office chairs: BMI and contact area ($r = 0.62$), weight and contact area ($r = 0.61$), RPI and contact area ($r = 0.50$) and stature and contact area ($r = 0.48$). According to Moes (2007), who studied pressure in upright sitting without back support, there is also a correlation between the percentage of subcutaneous fat and the contact area of the seat pan. Vincent, Bhise, and Mallick (2012) found that the contact area in different seat regions (e.g. front half of the seat pan) could be predicted relatively well on the basis of cushion hardness and hip width, gender, weight and stature. When comparing older and younger drivers, Kyung and Nussbaum (2013) found that the average contact area at the right buttock was larger for the older drivers, which could be explained by different driving postures. To summarise, the highest correlation coefficients were found, in more than one study, for body mass with contact area, followed by stature with contact area. Furthermore, correlations were found for hip breadth, hip circumference, BMI and percentage of subcutaneous fat with contact area.

Six studies investigated effects of anthropometric variables on *mean pressure*. For agricultural machinery, Hostens et al. (2001) found a linear increase in mean pressure with BMI ($r = 0.88$) for sitting on seats with the feet unsupported. Gyi and Porter (1999) studied the correlation between anthropometry and pressure variables while driving a car. They found that the highest average pressure was in thin and tall males (with highest RPI), and found a positive correlation between weight and thigh pressure (no correlation coefficients reported). Furthermore, hip breadth was one of the independent variables that explains mean pressure in a multiple regression (Gyi and Porter 1999). Vincent, Bhise, and Mallick (2012) found that weight, stature and buttock–popliteal length were the best predictors of average pressures. Additionally, Moes (2007) found that gender was the best predictor of average pressure (mult. $r = 0.75$), with the average pressure being lower for females than for males, and explains this by the lower mass in combination with a larger contact area for women. Lower mass, in turn, is correlated with a lower sitting force (Moes 2007; Paul, Daniell, and Fraysse 2012). Furthermore, Kyung and Nussbaum (2013) found that the average contact pressure at the lower back was higher for younger drivers compared to older drivers.

The effect of anthropometric variables on *peak or maximum pressure* was described in five studies. Hostens et al. (2001) found no correlation between BMI and maximum pressure, just as Jackson et al. (2009), who studied the effects of anthropometric variables on peak pressure of glider pilot seats. They did not find a relationship between weight, stature or BMI and peak pressure. This can be explained by the small variation in anthropometrics of the subjects, as all of them were UK glider pilots (Jackson et al. 2009). Moes (2007) found that the ectomorphic index (which is one of the indexes of the somatotype classification) was the only explaining variable of maximum pressure (mult. $r = 0.73$). Although the maximum pressure could not be predicted as good as the average pressure, weight, stature and buttock–popliteal length were, again, the best predictors (Vincent, Bhise, and Mallick 2012). In addition, Kyung and Nussbaum (2013) found significant effects of age on average peak pressure ratio at the upper back, which was higher for younger drivers.

A number of studies also included less common pressure variables, such as circular pressure gradient, transverse pressure gradient (Moes 2007) and pressure factor (a combination of pressure variables, derived from a principle compound analysis) (Vos et al. 2006). Moes (2007) found that the ectomorphic index and stature were the explaining variables for the transverse pressure gradient (mult. $r = 0.90$), and that the ectomorphic index was the only explaining variable for the circular pressure gradient (mult. $r = 0.80$). Vos et al. (2006) found correlations between BMI and pressure factor ($r = 0.31$), weight and pressure factor ($r = 0.44$) and stature and pressure factor ($r = 0.38$). Park et al. (2013) did not find significant effects of car driver's gender on pressure distribution of upper body parts (i.e. back and lumbar).

In conclusion, several studies report correlations between anthropometric variables and different variables of pressure. Age was found to influence posture and, therefore, pressure distribution. Most commonly studied pressure variables were contact area, average pressure and peak pressure. A larger contact area can be explained by higher weight and greater stature. A higher average

Table 1. Overview of studies in which some measures for anthropometry and some pressure variables were obtained.

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
Vos et al. (2006)	BMI (kg/m^2)	Contact area (active cell count)	r = .62	*N* = 24 (12 males; 12 females) participants compared 12 different office chairs	Moderate significant correlations were observed between active cell counts and BMI, mass, RPI and stature
	Mass	Contact area (active cell count)	r = .61		
	RPI (kg/m^3)	Contact area (active cell count)	r = .50		Pressure factor (combination of peak and average pressure) was moderately correlated with mass and stature, with weak but significant correlations observed for BMI and RPI
	Stature	Contact area (active cell count)	r = .48		
	Mass	Pressure factor	r = .42		
	Stature	Pressure factor	r = .38		
	BMI (kg/m^2)	Pressure factor	r = .33		Females experienced lower pressure factor values than males
	RPI (kg/m^3)	Pressure factor	r = -.21		
	Gender	Pressure factor	?		
Hostens et al. (2001)	BMI	Mean pressure	$R^2 = .8881$	4 foam and 1 air-based agricultural machinery seats *N* = 10 males	Almost linear relationship between mean pressure and BMI
		Peak pressure	No significant correlations	4x2 min. sitting per seat with 2–min. breaks, with feet hanging free	No significant correlation of BMI with peak pressure
Jackson et al. (2009)	BMI	Peak pressure	No significant correlations	5 different glider seat cushions	No significant correlation found between BMI, stature, mass and mean peak pressure
	Stature	Peak pressure	No significant correlations	*N* = 35 (15+20) male glider pilots <1.85m	
	Mass	Peak pressure	No significant correlations	1.5 h simulated flight	
Kyung and Nussbaum (2008)	Body stature (short/medium/tall)	Average contact area right buttock	The tall group had larger contact area at the right thigh	Car driver's seats	Significant ($p < .046$) stature effects were found only on the three pressure variables that were related to average contact areas and ratio
		Average contact area upper back	The tall group had larger contact area at the upper back	*N* = 27 (12 males, 15 females)	
		Average contact area ratio (upper back/sum)	The tall group had larger contact area ratios at the upper back	6 driving sessions, 15-20 min. each 2 × 2 × 2 design (seat x vehicle class x driving venue)	
Paul et al. (2012)	Body mass	Total contact area seat	Significant correlations for 3 cars in the range r = 0.413-0.856	*N* = 64 participants were randomly assigned to 1 of 3 vehicles for pressure measurements	Body mass and hip circumference were the best indicators for cushion contact area and for cushion front and rear force
		Total contact area rear cushion	Significant correlations for 3 cars in the range r = 0.432-0.741		Body mass and shoulder breadth were the best indicators for seat back contact area and upper seat back contact area
		Total force rear cushion	Significant correlations for 3 cars in the range r = 0.452-0.605		
		Total force front cushion	Significant correlations for 3 cars in the range r = 0.589-0.666		
		Total contact area seat back	Significant correlations for 3 cars in the range r = 0.611-0.895		
		Total contact area lower seat back	Significant correlations for 2 cars in the range r = 0.568-0.832		
		Total contact area upper seat back	Significant correlations for 3 cars in the range r = 0.440-0.688		
	Hip circumference	Total contact area seat	Significant correlations for 3 cars in the range r = 0.494-0.866		

		Total contact area rear cushion	Significant correlations for 3 cars in the range r = 0.546-0.592		
		Total force rear cushion	Significant correlations for 2 cars in the range r = 0.479-0.501		
		Total force front cushion	Significant correlations for 3 cars in the range r = 0.446-0.694		
	Hip breadth	Total contact area seat	Significant correlations for 2 cars in the range r = 0.734-0.847		
		Total contact area rear cushion	Significant correlations for 2 cars in the range r = 0.638-0.640		
		Total force rear cushion	Significant correlations for 2 cars in the range r = 0.452-0.467		
		Total force front cushion	Significant correlations for 3 cars in the range r = 0.477-0.580		
	Sitting knee height	Total contact area seat	Significant correlations for 1 car: r = 0.498		
		Total contact area rear cushion	Significant correlations for 2 cars in the range r = 0.406-0.463		
		Total force rear cushion	No significant correlations		
		Total force front cushion	Significant correlations for 1 car: r = 0.481		
	Buttock knee length	Total contact area seat	Significant correlations for 2 cars in the range r = 0.399-0.533		
			Significant correlations for 1 car: r = 0.452		
		Total force rear cushion	Significant correlations for 1 car: r = 0.432		
		Total force front	Significant correlations for 1 car: r = 0.408		
	Sitting height	Total contact area seat back	No significant correlations		
		Total contact area lower seat back	Significant correlations for 1 car: r = 0.396		
		Total contact area upper seat back	No significant correlations		
	Shoulder breadth	Total contact area seat back.	Significant correlations for 3 cars in the range r = 0.536-0.806		
		Total contact area lower seat back	Significant correlations for 2 cars in the range r = 0.598-0.749		
		Total contact area upper seat back	Significant correlations for 3 cars in the range r = 0.365-0.621		
	Sitting shoulder height	Total contact area seat back	Significant correlations for 1 car: r = 0.552		
		Total contact area lower seat back	Significant correlations for 1 car: r = 0.514		
		Total contact area upper seat back	Significant correlations for 3 cars in the range r = 0.424		
Moes (2007)	Somatotype, subcutaneous fat, stature, body mass, thigh depth at level buttock fold, distance between SIPS (breadth)	Transverse pressure gradient (discerns between medial and lateral components)	Transverse pressure gradient is predicted by ectomorphic index and stature (mult. r = 0.80)	*N* = 20 Laboratory flat measuring seat without back support. The influence of pelvic rotation and anthropometric variables on pressure variables was analysed through multiple regression analysis	A significant influence of somatotype on max. pressure, and significant but smaller contribution of stature on the pressure gradient was found. Ectomorphy rating and stature are explaining variables of circular pressure gradient. Ectomorphy rating is the only explaining variable of both transverse pressure gradient and max. pressure.

(*Continued*)

Table 1. (*Continued*).

Reference	Anthropometric variables	Pressure variables	Correlation	Study design	Conclusions
	Somatotype, subcutaneous fat, stature, body mass, thigh depth at level buttock fold, distance between SIPS (breadth).	Maximum pressure	Maximum pressure predicted by ectomorphic index (mult. r = 0.73)	*N* = 20 Laboratory flat measuring seat without back support. The influence of pelvic rotation and anthropometric variables on pressure variables was analysed through multiple regression analysis	Several pressure variables can be predicted by different anthropometric variables or a combination thereof. It is remarkable that average pressure is predicted only by gender. This implies that average pressure is mainly dependent on gender. It can therefore be a co-variable in the relationship between anthropometric variables and average pressure; however, this analysis was not performed
		Circular pressure gradient	Circular pressure gradient predicted by the ectomorphic index and stature (mult. r = 0.90)		
		Size of contact area	Distance between SIPS and subcutaneous fat (mult r = 0.81)		
		Sitting force	Sitting force predicted only by mass (r = 0.91)		
		Average pressure	Average pressure predicted only by gender (mult. r = 0.75)		
Gyi and Porter (1999)	Gender, hip breadth, weight, RPI	Mean pressure for different areas	Hip breadth and gender were selected as best predictors of mean pressure under IT in multiple regressions (mult r not reported). Buttock discomfort, sitting height and hip breadth explained 99% (mult r = 0.99) of the variance in mean IT area pressure. The highest average IT pressures were found for tall and thin males (with highest RPI). Positive correlations were found between weight and thigh pressure.	Experiment 1: *N* = 14 participants (representing a wide range of statures) sat on their most preferred and least preferred car seat (out of 7 seats) for a 2.5–hour static drive Experiment 2: *N* = 12 participants (representing a wide range of statures) sat on the most overall preferred seat from experiment 1 for a 2.5–hour static drive	Gender and hip breadth are best predictors of mean IT pressure; thinner subjects (lower RPI) had higher IT pressures
		Average seat ratio (ratio between seat mean and back mean)			No associations reported
		Maximum pressure for different areas			No associations reported
		Standard deviation of the mean pressure for different areas			No associations reported
		Pressure area for different areas			No associations reported
Park et al. 2013	Gender	Seating pressure ratio (in %) of 17 body parts (9 for seat back and 8 for seat pan pressure)	No significant effect	*N* = 40 (20 male, 20 female) car drivers in driving simulation experiment	No significant correlations between gender and seating pressure
Kyung and Nussbaum 2013	Age	Mean contact area and ratio (local measure relative to sum) for 6 body parts: left/right thigh, left/right buttock, lower/upper back	Older drivers had a 12.9% higher value for mean contact area at the right buttock Younger drivers had a 7.3% higher value for contact area ratio at left thigh	*N* = 22 car drivers, divided into 2 age groups: older (≥60 years, *N* = 11) and younger (20-35 years, *N* = 11)(6 male, 5 female per group) 6 driving sessions: combination of vehicle class (SUV/sedan), driving venue (lab/field), and seat (high/low comfort score)	A significant effect of age was found for 4 of 36 pressure measures; different loadings were due to postural differences between older and younger drivers
		Mean contact pressure and ratio (local measure relative to sum) for 6 body parts	Younger drivers had a 30.8% higher value for mean contact pressure at lower back		
		Mean peak pressure and ratio (local measure relative to sum) for 6 body parts	Younger drivers had a 13.9% higher value for peak pressure ratio at upper back		

Note: The conclusions regarding the relationships between these variables are described in the last column.

pressure can be explained by a higher weight. However, gender seems to affect this relationship, as the contact area for women is larger (due to larger hip breadth). Besides weight and stature, buttock–popliteal length was found to be a predictor of average and maximum pressures. Peak pressure is best explained by the score on the ectomorphic index of the somatotype classification.

3.1.2. Seat characteristics and their influence on mediating variables

Seat characteristics can be divided into seat dimensions, shape of the seat and material of the seat cushions. Their associations with the mediating variables are described in the following subsections.

3.1.2.1. Effects of seat characteristics on posture and movement. Various seat characteristics can affect body posture and movement while sitting. Of course, the angles of the backrest and the seat pan determine the overall body posture, such as the trunk–upper leg angle. However, some seat characteristics have a more subtle effect. Five studies were found that studied these relationships.

Telfer, Spence, and Solomonidis (2009) used an activity monitor to measure the *movements* of 12 participants who were sitting on four different seats. Although they found a significant difference between the four seats for postural changes, it remained unclear which of the seat characteristics were responsible for these differences as the seats differed in dimensions, as well as in materials and shape.

The effect of *seat shape* on *body posture* has been studied by Noro et al. (2012). In their study on surgical seats, they found that the seat shape following the contour of the buttock and providing sacral support led to more pelvic tilt compared to a seat without sacral support. Park et al. (2013) observed that the sitting strategy adopted for lower body was influenced by car driver's seat height (determined by occupant package layout). The posture with knees bent predominantly occurred in the SUV condition (seat height = 305 mm), but hardly occurred in the coupé condition (seat height = 176 mm), whereas the posture with the knee extended hardly occurred in the SUV condition, but did appear in the coupé and sedan (seat height = 240 mm) conditions. In a study on supporting the use of a tablet device, Van Veen et al. (2014) showed that the neck flexion angle of passengers could be significantly reduced when using specially designed armrests, thereby increasing the ratings for overall comfort, and comfort ratings for the neck region specifically.

Van Deursen et al. (2000) developed a special seat that induced passive motion of the spine while sitting. This special seat feature caused passive movements of the body that lengthened the spine in order to reduce discomfort in sitting.

These studies show that seat characteristics affect body posture and movement. As all seats will cause discomfort over time, it is important that the seat should provide the possibility to adopt different body postures in order to reduce discomfort (Van Rosmalen et al. 2009).

3.1.2.2. Effects of seat characteristics on interface pressure. Nine out of the 10 studies discovered associations between seat dimensions or seat shape and interface pressure. None of the studies reported a correlation between the material of the seat cushions and interface pressure.

Five studies reported associations between *seat dimensions* and *interface pressure*. Kyung and Nussbaum (2008) found significant effects of different seats on pressure variables, such as average pressure on buttock and thigh, peak pressure on buttock and thigh and contact area on buttock and thigh. This may be due to the different dimensions of the tested seats, but may also be caused by different shapes and cushion materials. According to Reed et al. (2000), cushion length is an important determinant of thigh support. A cushion that is too long can put pressure on the posterior portion of the occupant's legs near the knee. Pressure in this area will lead to local discomfort and restrict blood flow to the legs. This finding is supported by Mergl (2006), who defined the ideal pressure distribution for car driver's seats. He showed that comfort is rated high when there is an ideal pressure distribution under the legs and buttocks, namely 24.5–28.5% of the total load for both left and right buttocks, less than 14% of the total load for the thighs and less than 3% of the total load for the front of the thighs. The shape of the seat pan can contribute to this ideal pressure distribution. Additionally, Hostens et al. (2001) found that a smaller backrest inclination angle leads to higher sub-maximum pressures on the seat pan and smaller sub-maximum pressures on the backrest. However, Park et al. (2013) did not find significant effects of car driver's seat height (determined by occupant package layout) on pressure distribution of lower body parts (i.e. buttock and thighs).

Another five studies reported associations between the *shape of the seat* and *interface pressure*. According to Chen et al. (2007), different shapes of cushions lead to different pressure distributions. Carcone and Keir (2007) studied the effects of anthropometry (individual size and stature) on backrest preference, but found no significant effects. Andreoni et al. (2002) analysed pressure and comfort in a larger number of seats with different shapes and foam stiffness, and defined correlations with the shape of the human body at the interface measured by the imprinted surface. Using this method, it was possible to find an optimum shape and stiffness of the foam. Noro et al. (2012) found a larger contact area and lower average pressure for a prototype of surgical seat that followed the buttock–sacral contour of the human body compared to a conventional surgical seat. In a comparison of nine different office chairs, Zemp, Taylor, and Lorenzetti (2016) concluded that material properties and shape of the cushions strongly influence pressure distribution measurements. Therefore, they suggest chair-specific sensor calibration before analysing and comparing different chairs.

Although none of the studies calculated correlations between seat characteristics and interface pressure, their results do show associations between seat dimensions, seat shape, seat material and interface pressure; however, the exact relationships are unclear.

3.1.3. Context characteristics and their influence on mediating variables

The activity that passengers perform is considered the main context characteristic. Hence, the effects of performed activities on body posture, movement and interface pressure are described in the following subsections.

3.1.3.1. Effect of performed activities on posture and movement. Different sitting *postures* are associated with different *tasks and activities*. An overview of the relationships between tasks and activities and the corresponding postures and/or posture shifts is presented in Table 2. According to three studies, in which activities and tasks performed in offices, in semi-public situations (i.e. private spaces accessible to the general public) and on trains were observed (Ellegast et al. 2012; Kamp, Kilincsoy, and Vink 2011; Groenesteijn et al. 2014), different activities or tasks have related sitting postures that are significantly different from each other. Additionally, there is a tendency for typical activity-related postures to be chosen in relation to the perceived comfort (Groenesteijn et al. 2012) and due to the task demands (Lueder 2004). Temporal variations like posture shifts or movements also depend on the task or activity performed as reflected in the significant differences between tasks and activities (Graf, Guggenbühl, and Krueger 1995; Babski-Reeves, Stanfield, and Hughes 2005; Commissaris and Reijneveld 2005; Groenesteijn et al. 2012). Hence, tasks or activities determine both postures and posture shifts.

Several studies investigated which postures are seen in public transport regarding the tasks people perform in that situation. Kamp, Kilincsoy, and Vink (2011) studied the interaction between body postures and activities in semi-public situations and during a train journey. They found a significant relationship between most activities and the position of the head, trunk and arms during transport: in low-level activities (sleeping, relaxing and watching), the head was supported in 49% of the observed situations, whereas in medium-level activities (reading, talking and eating/drinking) and high activity levels (using small or larger electronic devices), this was only in 39% and 36% of the observed situations, respectively. The trunk position varied mostly in the low-level activities (free of support, against backrest or lounging); however, in the medium-level and high-level activities, it was mostly straight against the backrest. Except for just the elbow on the armrest, which was not observed in low-level activities, differences in using the armrest were less clear between the activity levels.

Groenesteijn et al. (2014) found that the posture with the highest comfort ratings was a slumped posture, with the head against the headrest. This posture occurred in all four most frequently observed activities: reading, staring/sleeping, talking and working on a laptop. The next most common posture was straight up, with the back against the backrest and the head against the headrest (observed in reading, staring/sleeping and working on a laptop). For reading and working on a laptop, the same position for the back was observed in combination with a bent neck (Groenesteijn et al. 2014). For watching television (comparable to watching in-flight entertainment), it has been shown that a more backward rotated backrest is preferable (Van Rosmalen et al. 2009). Additionally, if the theory of Goossens and Snijders (1995) is applied to prevent shear forces (i.e. friction that occurs in the contact surface between the human and seat), a tilted seat with the front of the seat upwards is a consequence of this posture. Gscheidle, Miller, and Reed (2004) describe a variation in observed backrest angles of between 20° and 40° backwards for one task (office work), while Park et al. (2000) describe a variation of between 103° and 131° in observed trunk–thigh angle of Koreans while driving a car.

It can be concluded from these studies that the task or activity that people perform affects their posture. However, due to the nature of the measurements (often observational studies), no quantitative relationships can be described.

3.1.3.2. Effect of performed activities on interface pressure. No studies were found that describe the direct association between performed activities and interface pressure. Earlier, it was concluded that posture is dependent on the task or activity, and that posture is associated with interface pressure. This is probably the reason that no studies were found that describe a direct relationship between activities and interface pressure.

3.2. Interdependencies of the mediating variables

The mediating variables, posture, movement and interface pressure, and their influence on each other are described in this section.

Table 2. Overview of studies found in which people performed different activities and some observations or measures of sitting body posture were obtained.

Reference	Activity variables	Posture variables	Study design	Conclusions
Kamp, Kilincsoy, and Vink (2011)	Sleeping	Head, trunk, arms and legs	Momentary observations $N = 743$ on trains and in semi-public situations	Significantly different posture of head against headrest, trunk slumped and arms upon armrest and uncrossed feet
	Relaxing			Significantly different posture of head against headrest or supported by hands, trunk slumped and arms upon armrest
	Watching			Significantly different posture of head unsupported, trunk free or against backrest and arms free from armrest
	Reading			Significantly different posture of trunk against backrest and arms free from armrest
	Talking			Significantly different posture of head free of support and arms free from armrest
	Using small electronic devices			Significantly different posture of head free or against backrest and arms free from armrest
	Eating/ drinking			Significantly different posture of head unsupported, trunk free from backrest or slumped
	Working – using larger electronic devices			Significantly different posture of head unsupported and trunk free or against backrest
Graf, Guggenbühl, and Krueger (1995)	Computer programming compared to general office work	Variation in postures	Postures at 5 workplaces	Computer programming workers have less variability in postures in comparison to general office workers
Lueder (2004)	Use of screen and input devices	Sitting postures	Office chairs ergonomic review study	Visual demands of the task and the reach distances can play a role in leaning forward
Ellegast et al. (2012)	7 standardised office tasks	Postures/joint angles	Office chairs, $N = 10$	Many significant effects of performed tasks on postures and joint angles
Groenesteijn et al. (2014)	Staring/sleeping	Body part positions of head, trunk and seat contact and comfort score in relation to activity on 10-point scale	Top 4 of most observed activities during momentary observations $N = 786$ and journey observations $N = 30$ on trains	Tendency highest comfort score with posture: head straight up, trunk straight and up and full seat contact
	Reading			Tendency highest comfort score with posture: head straight up, trunk backwards and full seat contact
	Talking			Tendency highest comfort score with posture: head sideward, trunk backwards and full seat contact
	Working			Tendency highest comfort score with posture: head forward, trunk straight and up and full seat contact
Babski-Reeves, Stanfield, and Hughes (2005)	Standard data entry (typing task)	Posture shifts	Office work station, $N = 8$	Significant larger number of neck posture shifts with data entry task compared to math task
	Simple math calculations	Posture shifts		Significant larger number of feet posture shifts with math task compared to data entry task
	Task repetition *(set of times each task was completed within each session)*	Posture shifts		Significant increase in posture shifts across task repetitions
Groenesteijn et al. (2012)	Computer work	Postures/joint angles, physical activity of body parts	Office chairs field study, $N = 12$	Lowest physical activity in all body parts, together with upright trunk, upright head position and low backrest inclination
	Telephoning			Medium physical activity and the highest kyphosis
	Conversation			Highest activity of head and legs, and the highest cervical spine extension
	Desk work			The second lowest activity, most cervical spine flexion

Note: The conclusions regarding the relationships between these variables are described in the last column.

3.2.1. Interdependencies between interface pressure and posture

Ten studies measured the relationship between *posture* and *interface pressure*. Vos et al. (2006) studied the effect of personal factors, posture and seat design on interface pressure in ergonomic office chairs. They found that an increased trunk–thigh angle reduced the pressure factor values (i.e. a combination of peak pressure and average pressure). Moes (2007) found that pelvis rotation affects the contact area and the average pressure in upright sitting without a backrest. The relationship between pelvis rotation and contact area is affected by anthropometric characteristics, such as subcutaneous fat and endomorphic index (Moes 2007).

Tessendorf et al. (2009) employed pressure distribution patterns acquired from a pressure mat to generate 16 prototype sitting postures which they then used to classify incoming pressure data. This way, the sitting posture could be predicted in real time from pressure data. The classification performance was studied and, on average, the assignment of a posture to a prototype sitting posture was achieved in 91% of the cases. In 86% of the cases, an unambiguous assignment of a posture to a prototype sitting posture was achieved (Tessendorf et al. 2009). Likewise, Xu et al. (2012) developed a method to recognise nine different seating postures on the basis of binary pressure distribution data. They achieved an accuracy of 82.3% using 64 pressure sensors (6 × 8 sensors for the seat pan and 2 × 8 sensors for the backrest) with a threshold of 3 N.

Zhiping and Jian (2011) studied three sitting postures induced by three inclination angles of the backrest of an office seat. They found significant effects of different postures on six pressure variables (average seat pan pressure, peak seat pan pressure, average backrest pressure, peak backrest pressure, back contact area and back load). In a study by Oyama et al. (2003), an upright sitting posture was compared to a reclined sitting posture for a 20-min typing task. They also found significant differences for the mean seat pan pressure (which was lower in the reclining group) and mean backrest pressure (which was higher in the reclining group), and showed that there is a relationship between the pelvic angle and the seat pressure pattern. Results of a study by Kyung and Nussbaum (2013) also show that postural differences in car driver seats led to differences in pressure measurements. For example, peak pressure ratio at the upper back was higher in a SUV seat configuration, indicating that a more upright posture provided more support for the upper back than a more reclined posture (sedan seat configuration). This seems to be in contrast with Chen et al. (2013), who found that increasing the back rest angle increases pressure values at the back rest and reduces pressure values of the seat pan due to the shifting of body weight (centre of gravity) towards the back rest. On the other hand, Park et al. (2013) analysed the relative pressure ratio of 17 body parts, and found no relationship between driving posture and seating pressure. Similarly, Zemp, Taylor, and Lorenzetti (2016) conclude that the differences in seat pan and backrest pressure parameters that they measured could be due to the differences between seats, the adjustments or between the specific postures of each participant for three different positions (upright, reclined and forward inclined).

These studies show that interface pressure is correlated with body posture. However, effect sizes were not reported in any of the studies.

3.2.2 Interdependencies between interface pressure and movement

Change in interface pressure is also used as an indicator of change in body posture, namely the amount of movement. This has been the topic of three studies. Wang et al. (2011) studied the effect of movements on pressure variables in car seats. The aim of their study was to distinguish between movements that drivers make in order to drive a car and those that they make to reduce discomfort over time. Their study proved that the seat pressure variables are sensitive to driving movements. Ciaccia and Sznelwar (2012) studied the postures and interface pressure of two activities (resting and reading) in an aeroplane in only five subjects. The combination of a pressure map and its corresponding posture (the postures had been visually recorded) gave an insight into the alterations of body postures over time for each activity. The study by Ciaccia and Sznelwar (2012) presents only qualitative observations, but the study by Na et al. (2005) provides scientific support. The latter used body pressure change variables – which count the number of large changes in body pressure – as indicators of movement. They found that, when the driving period increased, the body pressure change variables increased, along with the ratings of discomfort.

It can be concluded from these studies that interface pressure can be an indication of alterations of body postures and thus of movement.

3.3 Effects of mediating variables on comfort and discomfort

This section describes the influence of the mediating variables, posture, movement and interface pressure, on passengers' perception of comfort and discomfort.

3.3.1 Effects of posture and movement on comfort and discomfort

Seven studies indicated that the human body seems to compensate for discomfort by changing body posture or making postural movements. Body pressure change variables and subjective discomfort ratings were found to increase when the driving period increased. This implies that the driver tends to move more frequently when he feels discomfort (Na et al. 2005). Similarly, when measuring pressure distribution of two automotive seats, Le et al. (2014) noticed that discomfort led to movement. For glider pilots, Jackson et al. (2009) found that, after about 40 min, pilots began to make large fidgeting movements to relieve buttock pressure. In another study, by Sember (1994), it was found that it took at least 30 min for discomfort to become sufficient for a behavioural response to occur. Movements are therefore also used as an indication of discomfort. Telfer, Spence, and Solomonidis (2009) concluded that postural movement explained 29.7% of the variance in discomfort, and Søndergaard et al. (2010) reported that the standard deviation of the movement of the centre of pressure is correlated to discomfort. This is also supported by results from the study by Cascioli et al. (2016), presenting a methodology using in-chair movements (ICM) to measure discomfort. Their findings indicate a positive relationship between ICM and discomfort, i.e. discomfort increases when ICM increase.

On the other hand, movements could also be used to prevent discomfort over time and to create comfort. Both active and passive motion during sitting seem to have a positive effect on comfort as well as decrease discomfort (Hiemstra-van Mastrigt et al. 2015; Van Dieën, De Looze, and Hermans 2001; Van Deursen et al. 2000; Franz et al. 2012). Discomfort in sitting occurs due to prolonged and monotonous low-level mechanical load imposed by a seated posture (Van Dieën, De Looze, and Hermans 2001). Several studies have shown that passive motion has positive effects on preventing discomfort in office seats (Van Deursen et al. 2000; Franz et al. 2012). Franz et al. (2012) showed that comfort was higher and the muscle activity of the trapezius area was significantly lower when driving with a massage system. Other studies focused on active dynamic sitting in office chairs (Van Dieën, De Looze, and Hermans 2001) and the rear seat of a car (Hiemstra-van Mastrigt et al. 2015). For example, car passengers felt more refreshed, more challenged and more fit after a 30-min drive when using an 'active seating system', i.e. if they had played a video game while driving that requires players to move their upper bodies (Hiemstra-van Mastrigt et al. 2015). Furthermore, several studies show the importance of alternating seated postures (e.g. Lueder 2004; Nordin 2004). Van Rosmalen et al. (2009) showed that a seat supporting a variety of postures when watching television is experienced as comfortable.

Hence, the relationship between movement and comfort and discomfort is twofold. On the one hand, several studies show that micro-movements and fidgeting are an appropriate measure for discomfort, even before the person is aware of discomfort. On the other hand, active seating can reduce discomfort and improve comfort.

3.3.2. Effect of interface pressure on comfort and discomfort

An overview of studies on the correlation between interface pressure and comfort and discomfort is presented in Table 3. Different variables were used to indicate the interface pressure on seat pan and backrest, such as contact area, average pressure, peak pressure, pressure gradient and pressure change. Furthermore, six studies divided the interface area into different parts, for instance, front thigh, middle thigh and buttocks (Porter, Gyi, and Tait 2003; Mergl 2006; Na et al. 2005; Gyi and Porter 1999; Noro et al. 2012; Kyung and Nussbaum 2008). The effects on comfort and discomfort were measured by different methods, such as discomfort and/or comfort ratings per body region, the number of discomfort-induced fidgeting movements and ranking between seats on comfort. The correlations found in the studies between interface pressure variables and comfort and discomfort are described below.

For *seat pan comfort,* Carcone and Keir (2007) found a tendency for larger contact areas to be associated with a higher ranking on comfort. For average and peak pressure, no significant relationship with comfort in lumbar, hip and thigh regions was found in interaction with car seats (Porter, Gyi, and Tait 2003). For *seat pan discomfort,* Noro et al. (2012) showed that lower average pressure is accompanied by less discomfort. Body pressure change variables increase along with whole body discomfort and local body part discomfort (including lumbar, hip and thigh) (Na et al. 2005). For glider pilots, Jackson et al. (2009) determined a mean peak pressure threshold of 8.8 kPa: below this pressure, no discomfort occurred. According to Chen et al. (2007), pressure should be highest underneath the central sitting bones (ischial tuberosity) and should dissipate towards the thighs and sides. Mergl (2006) found that the shape of the relationship between mean pressure and seat pan discomfort differs for different areas of the buttocks and upper legs. He found a quadratic relationship between the mean pressure and discomfort for the buttocks, and a linear relationship for the middle thigh and frontal thigh. The quadratic relationship implies that discomfort occurs when the mean pressure under the buttocks is either too low or too high. This means that an optimum of mean pressure values for the buttocks does exist. For the middle and the front thigh, the relationship is linear, which means that when the mean pressure increases, the perception of discomfort increases. Significant correlations between pressure and subjective ratings for car driver seats were reported by Kyung and Nussbaum (2013) for 22 of 36 pressure measures; the largest positive correlation ($\rho = .31$) was found between the contact pressure at the right buttock and discomfort ratings.

Table 3. Overview of studies in which some measures of pressure and measures of comfort and discomfort were obtained.

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
Mergl (2006)	Percentage of load of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10–17) with a CP50 scale	*Buttock:* Quadratic relationship; ≥15% and ≤25% of subjects had a significant relationship *Middle of thigh:* Linear relationship ≥50% of the subjects had a correlation coefficient r ≥ 0.81 *Front of thigh:* Linear relationship ≥50% of the subjects had a correlation coefficient r ≥ 0.81 *Side of thighs:* Linear relationship ≤15% of the subjects had a correlation coefficient r ≥ 0.81	*N* = 10 Six different settings of automobile seats were evaluated on pressure variables and discomfort	Depending on the body part region and the pressure variable, the relationship between interface pressure variables and body part discomfort can be either quadratic or linear. For some body parts (middle of thigh) and some pressure variables (percentage of load, mean pressure, maximum pressure) more evidence for a relationship was found than for others
	Maximum pressure of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by bodymap of seatpan (regions 10–17) with a CP50 scale	*Buttock:* Linear relationship ≥25% and ≤50% of the subjects had a correlation coefficient r ≥ 0.81 *Middle of thigh:* Linear relationship ≥50% of the subjects had a correlation coefficient r ≥ 0.81 *Front of thigh:* Linear relationship ≤15% of the subjects had a correlation coefficient r ≥ 0.81 *Side of thighs:* Linear relationship ≤15% of the subjects had a correlation coefficient r ≥ 0.81		
	Mean pressure of buttocks, middle thighs, front thighs and side thighs	Discomfort measurements by body map of seat pan (regions 10–17) with a CP50 scale	*Buttocks:* Quadratic relationship ≥25% and ≤50% of the subjects had a significant correlation *Middle of thigh:* Linear relationship ≥50% of the subjects had a correlation coefficient r ≥ 0.81 *Front of thigh:* Linear relationship ≥15% and ≤25% of subjects had a significant relationship *Side of thighs:* No relationship found		
	Pressure gradient of buttocks, middle thighs, front thighs and side thighs		*Buttocks:* Linear relationship ≥15% and ≤25% of subjects had a significant relationship *Middle of thigh:* Linear relationship ≥25% and ≤50% of the subjects had a correlation coefficient r ≥ 0.81 *Front of thigh:* Linear relationship ≥15% and ≤25% of subjects had a correlation coefficient r ≥ 0.81		
Carcone and Keir (2007)	Mean peak backrest pressure	Comfort ranking of backrests	Lower peak backrest pressure was associated with higher ranked backrests.	*N* = 30	No correlations calculated
	Backrest contact area		Smaller backrest contact area was associated with higher ranked backrests	Participants were seated at a computer workstation in 5 backrest conditions: chair only, chair with backrest, chair with backrest with each of three lumbar pad thicknesses	Only qualitative associations were described of some pressure variables and ranking of backrests
	Seat pan contact area		Greater seat pan contact area was associated with higher ranked backrests.		

Noro et al. (2012)	Peak pressure and pressure area of 6 body parts (sacral area, ischial area, left and right lateral area of buttocks, left and right thigh)	Senses of comfort of body parts on a 5–point scale of sacral, ischial and thigh body parts and other items, like sliding	No correlations between pressure variables and subjective measures available	$N = 11$ participants sat on two different surgical seats during surgical operations: a conventional seat and a prototype of a new seat	The average pressure on the seat pan was lower for the preferred seat
Na et al. (2005)	Body pressure ratio (sum of body pressures per region divided by sum of body pressures of lumbar and buttocks region). Body pressure change variables (number of pressure changes exceeding 15 % of the average total pressure for the back and 5% of the seat pan) indicating the number of subject's movements.	Body part discomfort ratings of neck, shoulder, back, lumbar, hip and thigh on a 7-point scale	Body pressure change increased as the driving period increased. The same tendency was found in whole body part discomfort level. Furthermore, the same interaction effect was found of stature group and lumbar support for both body pressure change variables and body part discomfort.	$N = 16$ subjects sat on a seat of a mid-size sedan in Korean automobile market in a seating buck, driving a simulated track course consisting of 15 laps of 3 minutes per lap	No correlations were calculated. A tendency for association was found between body pressure change and body part discomfort
Kyung and Nussbaum (2008)	Average contact areas of different regions (upper/lower back, left/right buttock, left/right thigh) and ratios of a specific region divided by the total contact area	Overall ratings of comfort and discomfort on VAS scale with discomfort and comfort as extremes; separate whole body comfort and 6 local body parts (left/right thighs, left/right buttocks, upper/lower back) and discomfort rating of the 6 local body parts on a scale ranging from 0 to 10 for comfort and from 0 to -10 for discomfort.	*Overall comfort and discomfort rating* Significant correlations were found between the average contact area *ratio of the right thigh* with the overall comfort and discomfort rating ($r = 0.16$). For the other regions, no correlations were found. *Whole body comfort rating* Significant correlations were found between average contact area of the *left thigh* with whole body comfort rating ($r = -0.20$), for the *ratio of the left thigh* and the whole body comfort rating ($r = -0.20$). For the other regions no correlations were found. *Whole body discomfort rating* No correlations were found	$N = 27$ participants completed 6 short (25–20 min) driving sessions	Correlations were found between several pressure variables and ratios and overall comfort and discomfort rating and with whole body comfort rating No correlations were found between pressure variables and local body part discomfort rating
	Average contact pressures of different regions (upper/lower back, left/right buttock, left/right thigh) and ratios of the average contact pressure of a specific region divided by the average contact pressure of the total area	Overall ratings of comfort and discomfort on VAS scale with discomfort and comfort as extremes; separate whole body comfort and 6 local body parts (left/right thighs, left/right buttocks, upper/lower back) and discomfort rating of the 6 local body parts on a scale ranging from 0 to 10 and 0 to -10 for comfort and discomfort respectively.	*Overall comfort and discomfort rating* Significant correlations were found for the *Buttock left* ($r = -0.30$), *buttock right* ($r = -0.28$) and for *the ratio of the left buttock* ($r = -0.23$) and *ratio of the right buttock* ($r = -0.22$), and the *ratio of the lower back* ($r = 0.16$) and the *ratio of the upper back* ($r = 0.18$). For the other regions, no correlations were found. *Whole body comfort rating* Significant correlations were found for the *left thigh* ($r = -0.18$), *right thigh* ($r = -0.25$), *left buttock* ($r = -0.20$), *right buttock* ($r = -0.21$) and *upper back* ($r = -0.19$) and the *ratio of the lower back* ($r = 0.28$) For the other regions no correlations were found. *Whole body discomfort rating* No correlations were found	$N = 27$ participants completed 6 short (25–20 min) driving sessions	Correlations were found between several pressure variables and ratios and overall comfort and discomfort rating and with whole body comfort rating. No correlations were found between pressure variables and local body part discomfort rating.

(*Continued*)

Table 3. (*Continued*).

Reference	Pressure variables	Comfort and discomfort	Correlation	Study design	Conclusions
	Average peak pressures of different regions (upper/lower back, left/right buttock, left/right thigh) and ratios of a specific region divided by the peak pressure of the total area.	Overall ratings of comfort and discomfort on VAS–scale with discomfort and comfort as extremes; separate whole body comfort and 6 local body parts (left/right thighs, left/right buttocks, upper/lower back) and discomfort rating of the 6 local body parts on a scale ranging from 0 to 10 and 0 to -10 for comfort and discomfort respectively.	*Overall comfort and discomfort rating* Significant correlations were for the *right thigh* (r = -0.18), *left buttock* (r = -0.41), *right buttock* (r = -0.29), *upper back* (r = -0.28), *the ratio of the left thigh* (r = 0.19), *ratio of the left buttock* (r = -0.19), *ratio of the right buttock* (r = -0.16). For the other regions, no correlations were found. *Whole body comfort rating* Significant correlations were found for the *right thigh* (r = -0.16), *left buttock* (r = -0.24), *right buttock* (r = -0.17), *upper back* (r = -0.25), *ratio of lower back* (r = 0.16)For the other regions no correlations were found. *Whole body discomfort rating* No correlations were found		
Porter et al. (2003)	Mean pressure of 6 regions: left and right ischial tuberosity, left and right thighs, upper back and lower back.	Seat feature checklist and body part comfort scale of buttocks, thighs and lower back on a 7–point scale (ranging from very comfortable to very uncomfortable)	Car A: *Right thigh* and thigh comfort rating r = 0.52 (average over 3 measurement moments) Car B: *Upper back* and upper back comfort rating r = 0.61 (after a 135–min drive) and r = 0.58 (average over 3 measurement moments). For the other cars and variables, no significant correlations were found.	*N* = 18 participants participated in road trials and drove in 3 cars for 2.5 hours. Measurements after 15 and 135 min.	No clear relationship was found between interface pressure data and reported comfort/discomfort Five out of the six significant Spearman rank order correlation coefficients were from one car
	Maximum pressure of 6 regions: left and right ischial tuberosity, left and right thighs, upper back and lower back.		Car B: *Right thigh* and thigh comfort rating r = 0.57 (after 15 min drive) and r = 0.47 (average over 3 measurement moments) For the other cars and variables, no significant correlations were found.		
Chen et al. (2007)	Qualitative description of pressure distribution based on 3D pressure distribution images compared to the body pressure distribution rule	Subjective evaluation of 3 items: buttock comfort, thigh comfort, overall comfort on a 10–point scale (ranging from very uncomfortable to very comfortable)	When the pressure distribution is more like the body pressure distribution rule, the comfort score is higher.	*N* = 20 participants sitting on three different shaped seat cushions	No correlations were calculated
Zhiping and Jian (2011)	Average seat pan pressure, peak seat pan pressure, seat pan contact area, average back rest pressure, peak backrest pressure, back contact area.	Body-part discomfort of neck, shoulder, back, low back, hip and thigh on a 5–point scale (ranging from very strong to no discomfort) and overall discomfort (2 points: comfort or discomfort)	Lower back discomfort is significantly correlated with back contact area (r = 0.297), with peak backrest pressure (r = 0.235), and with backrest load (r=0.281).	*N* = 10 participants sat on 2 office chairs with the backrest in 3 inclination positions (90°, 110° and 130°)	Backrest pressure variables were correlated with lower back discomfort; however, correlation coefficients were low
Søndergaard et al. (2010)	Mean centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time	BPD index, i.e. sum of body part discomfort ratings on a 6–point scale ranging from 0 to 5 (no discomfort to worst imaginable discomfort)	No correlations between mean $COP_{A\text{-}P}$ and $COP_{M\text{-}L}$ with BPD	*N* = 9 participants watched a movie whilst sitting on a force platform with no back- or foot support, no armrest and no cushions for 90 min.	Correlations were found between centre of pressure displacement and discomfort, which indicates when discomfort increases, the sitting movement patterns became larger and more regular
	Standard deviation of centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time		Standard deviation of $COP_{A\text{-}P}$ is correlated with BPD (r = 0.273) Standard deviation of $COP_{M\text{-}L}$ is correlated with BPD (r = 0.239)		
	Sample entropy of centre of pressure (COP) displacement (anterior-posterior; medial-lateral) over time		Sample Entropy of $COP_{A\text{-}P}$ is correlated with BPD (r = -0.271) Sample Entropy of $COP_{M\text{-}L}$ is correlated with BPD (r = 0.278)		

Gyi and Porter (1999)	Average seat ratio (ratio between seat mean and back mean)	Body part discomfort on 7–point scale ranging from very comfortable to very uncomfortable for the right buttock, right thigh and the lower back	The only correlation that was found in experiment 1 was for female participants in their preferred seat: a negative correlation was reported between mean lower back pressure and lower back discomfort. No correlation coefficients were reported.	Experiment 1: $N = 14$ participants (representing a wide range of statures) sat on their most preferred and least preferred car seat (out of seven seats) for a 2.5–hour static drive.	Significant correlations were found between mean lower back pressure and lower back discomfort, and between buttock discomfort and IT area pressure variables, but no correlation coefficients were reported
	Maximum pressure for different areas		Significant correlations were found for the sample of tall males between buttock discomfort and IT area pressure variables (no correlation coefficient reported).	Experiment 2: $N = 12$ participants (representing a wide range of statures) sat on the most overall preferred seat from experiment 1 for a 2.5–hour static drive.	
	Mean pressure for different areas		No associations reported		
	Standard deviation of the mean pressure for different areas		No associations reported		
	Pressure area for different areas		No associations reported		
Kyung and Nussbaum (2013)	Mean contact area and ratio (local measure relative to sum) for 6 body parts: left thigh, right thigh, left buttock, right buttock, lower back, and upper back	Overall rating (combination of comfort and discomfort) Whole–body comfort rating Whole–body discomfort rating	Significant correlations were found for the lower back (ρ = -.20) with overall rating; for the left thigh (ρ = -.23), right thigh (ρ = -.20), right buttock (ρ = .21), and lower back (ρ = -.26-0.3) with whole–body comfort rating; for the left buttock (ρ = .17), right buttock (ρ = -.20), and upper back (ρ = -.20) with whole–body discomfort rating	$N = 22$ car drivers, divided into 2 age groups: older (≥60 years, $N = 11$) and younger (20-35 years, $N = 11$)(6 male, 5 female per group)	Significant correlations of weak to moderate effect were found with at least one of the subjective ratings for 22 out of 36 pressure measures (ρ ranges between -.26 and .31); the highest correlation (ρ = .31) was found between contact pressure at the right buttock and discomfort ratings
	Mean contact pressure and ratio (local measure relative to sum) for 6 body parts: left thigh, right thigh, left buttock, right buttock, lower back, and upper back		Significant correlations were found for the right thigh (ρ = -.21) with overall rating; for the right thigh (ρ = -.23), and upper back (ρ = -.22) with whole–body comfort rating; for the left thigh (ρ = .24), right thigh (ρ = .25), left buttock (ρ = .26), right buttock (ρ = .31), and lower back (ρ = .28) with whole–body discomfort rating	6 driving sessions: combination of vehicle class (SUV/sedan), driving venue (lab/field), and seat (high/low comfort score)	
	Mean peak pressure and ratio (local measure relative to sum) for 6 body parts: left thigh, right thigh, left buttock, right buttock, lower back, and upper back		Significant correlations were found for the right thigh (ρ = -.19-.26), lower back (ρ = .25) and upper back (ρ = -.19) with overall rating; for the right thigh (ρ = -.17-.23), lower back (ρ = .26) and upper back (ρ = -.24-.26) with whole–body comfort rating; for the left thigh (ρ = .24), right thigh (ρ = -.19), left buttock (ρ = -.18), lower back (ρ = .18), and upper back (ρ = .19) with whole–body discomfort rating		
De Looze et al. (2003)	Objective measures of comfort and discomfort, including pressure distribution	Subjective measures of comfort and discomfort		Literature review	Seven studies were found: three of them reported correlations (Yun et al. 1992; Thakurta et al. 1995; Vergara and Page 2000) between pressure variables and comfort or discomfort; two others (Kamijo et al. 1982, Tewari and Prasad 2000) reported associations

Note: The conclusions regarding the relationships between these variables are described in the last column.

For *backrest comfort,* Carcone and Keir (2007) found a tendency for the mean contact area of the backrest and average backrest pressure to be lowest for backrests that were preferred. Contrarily, Porter, Gyi, and Tait (2003) reported no significant relation for average pressure and comfort in the backrest area for car seats. Furthermore, they found no relationship between peak pressure and comfort in lumbar, hip and thigh regions. For *lower back discomfort*, Zhiping and Jian (2011) found a significant positive correlation with contact area of the backrest (high discomfort with large contact area), as well as a marginally positive correlation with backrest peak pressure load (high discomfort with high pressure). In addition, Mergl (2006) pointed out that the pressure distribution on the area of the seat pan underneath the buttocks had an influence on perceived discomfort in the lower back. Therefore, Mergl (2006) suggested that the material under the ischial tuberosity should be harder in order to prevent discomfort in the lower back.

For *headrest comfort*, Franz et al. (2012) showed that the preferred pressure on the neck is much lower than that on the back of the head. However, the positions of the back of the head with respect to the shoulders vary greatly between people, which makes a proper design of a neck/head rest even more complex.

In their literature review, De Looze, Kuijt-Evers, and Van Dieën (2003) concluded that pressure distribution appears to be the objective measure with the clearest association with subjective ratings of comfort and discomfort compared to other measures (such as measurements of body movements, estimations of muscle activation and muscle fatigue by electromyography and measurements of stature loss (spinal shrinkage) and foot/leg volume changes). Three of the seven studies found by De Looze, Kuijt-Evers, and Van Dieën (2003) reported significant correlations between pressure and comfort or discomfort, and two of the seven studies reported associations. Vincent, Bhise, and Mallick (2012) measured pressure distribution of four different cushions in an office armchair while subjects obtained automotive driving postures. They found significant but weak (correlation coefficients between 0.1 and 0.38) negative correlations between pressure and overall seat comfort ratings (i.e. lower pressure is correlated to higher comfort). Average pressure levels were slightly stronger correlated with overall comfort ratings than maximum pressure values in the seat cushion or seat back.

Pressure measurements are often used as indicators of comfort and discomfort. However, the explained variance in comfort and discomfort ratings by pressure is low. This is caused by many other factors that influence the pressure variables (such as anthropometrics and body posture), as well as by the other mediating factors that influence comfort and discomfort (i.e. posture and movement). Pressure measurements can be insufficiently sensitive to indicate differences between seats with different cushions, while the subjective comfort ratings are distinctive. This is supported by Porter, Gyi, and Tait (2003), who found significant differences between three car seats for mean pressure for only three areas (out of six) and for peak pressure for only one area (out of six).

3.4. Conceptual model

The conceptual model presented in Section 2.1 is further elaborated on human, seat and context level by the different variables that have been commonly used in previous studies (see Figure 3). Furthermore, the arrows illustrate the evidence that was found for the relationships between the variables. Three levels of evidence were distinguished in this way: statistically determined relationship (dark line), tendency for a relationship without statistical evidence (dashed line) and no studies available (light line).

4. Discussion

The aim of this study was to investigate the relationships between human, seat and context variables in order to predict passenger comfort and discomfort, and – if possible – to quantify the relationships between anthropometric variables, activities, postures, movement, interface pressure, and comfort and discomfort. This is important because of the increase in diversity of people who travel by plane and public transport, as well as the diversity of activities they perform due to societal and technological developments, such as globalisation and new IT technologies. Designers need to respond to these developments in their seat designs, and airlines and public transport organisations may distinguish themselves from their competitors by providing an optimal environment for their (potential) customers.

4.1. General remarks

A large majority of the studies found addressed the comfort and discomfort of car driver's seats and office chairs. The context of use (i.e. the performed activities) and the seat characteristics (adjustability of seat dimensions) for these areas are different compared to passenger seats for aircrafts or public transport. The main difference in both situations is the performed activity. For instance, driving a car imposes a fixed (asymmetric) body posture with hands on the steering wheel and one foot on the accelerator. Body postures in office work are mostly dictated by the adjustment of the chair, desk, screen and keyboard. This does not matter when more fundamental issues are studied (such as the relationship between pressure and

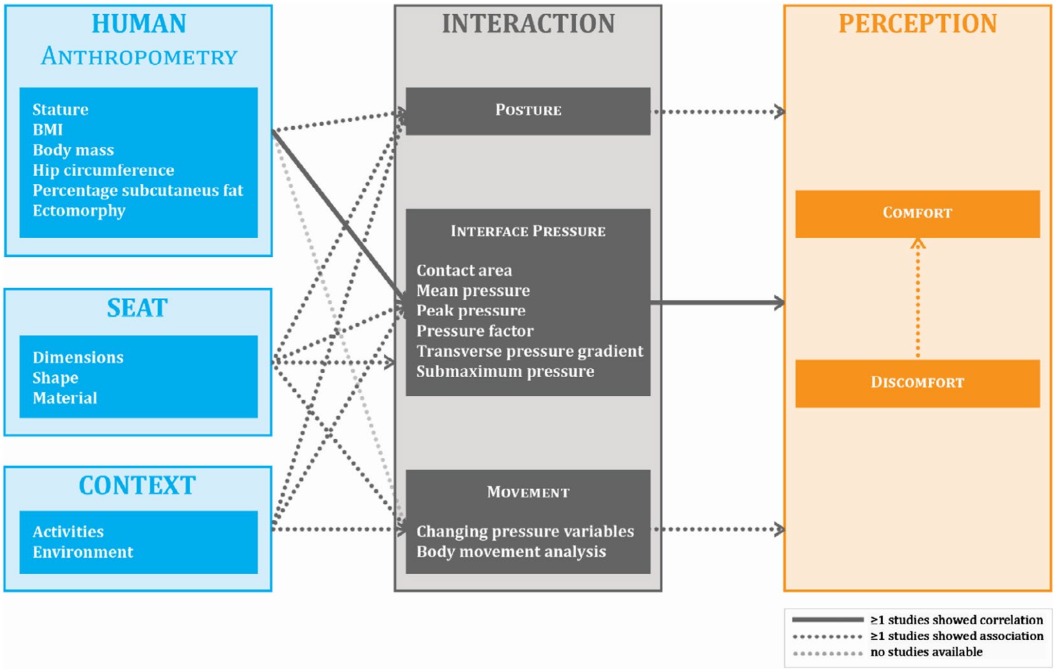

Figure 3. Overview of relationships between the variables.
Note: Differences in the level of evidence are indicated by the different arrow styles.

comfort and discomfort). However, it was found that body posture affects pressure variables (e.g. Vos et al. 2006; Tessendorf et al. 2009; Moes 2007; Zhiping and Jian 2011; Kyung and Nussbaum 2013), and that activities induce body postures (Ellegast et al. 2012; Kamp, Kilincsoy, and Vink 2011; Groenesteijn et al. 2012). This is why the studies focusing on car driver's seats should be interpreted with care. It is desirable to have more studies available in the area of passenger seats specifically.

In order to be able to build a predictive model, relationships between the variables need to be quantified. Therefore, statistical evidence is needed, such as correlation coefficients and effect sizes. However, only a few studies were found in which statistical evidence was found between variables. Furthermore, the different context characteristics (driver's seat, office chair and experimental seat) are hardly representative of passenger seats. It is therefore difficult, if not impossible, to generalise these data for the domain of passenger seats.

4.2. Effects of human, seat and context characteristics on perceived comfort and discomfort

As mentioned before, statistical evidence for many of the relationships studied in this review is lacking. Statistical evidence was found only for the correlations between anthropometric variables and pressure variables, and for those between pressure variables and comfort and discomfort. For the correlations between anthropometric variables and pressure variables, the highest correlations were found for contact area and average pressure with BMI, subcutaneous fat, hip width (gender) and somatotype. The study by Moes (2007) is the only study in which the relationship between anthropometric variables and pressure variables was investigated in relation to body posture. For instance, Moes (2007) found that the dependency of the average pressure on a rotation of the pelvis (in the sagittal plane) had a positive correlation with the endomorphic index, and that the dependency of the contact area on a rotation of the pelvis is negatively correlated with the percentage of subcutaneous fat. These findings imply that when studying the relationship between anthropometric variables and pressure variables, it is necessary to take into account pelvic rotation as well. This rotation may vary in different body postures from a slumped position to sitting upright. This also means that the correlations regarding this relationship found in the other studies cannot be directly translated into a predictive model without knowledge of the body posture and, more specifically, the pelvic rotation of the participants in these studies.

Although pressure measurements are often used to illustrate the seat quality or to indicate comfort and/or discomfort, no clear scientific evidence for this can be found in the literature. This is supported by the findings of Zemp, Taylor, and Lorenzetti (2015), who concluded that there are limited data available to determine whether pressure measurements are effective in the assessment of office chair comfort or discomfort. Some studies indicate an association between higher average or peak pressure and greater discomfort (e.g. Carcone and Keir 2007; Noro et al. 2012), and larger contact areas with less discomfort (e.g. Carcone and Keir 2007), but do not present any statistical proof. Others calculate correlation coefficients between average pressure and peak pressure and discomfort (e.g. Kyung and Nussbaum 2008; Porter, Gyi, and Tait 2003; Zhiping and Jian 2011). The variation between the reported correlation coefficients is large, even between subjects within one experimental setting, and of course between different scientific studies. On the one hand, this can be explained by the differences in measurement methods. Different subjective methods are used for measuring comfort and discomfort, and some authors even suggest that passenger comfort experience could be evaluated using one single scale (Ahmadpour, Robert, and Lindgaard 2016). In addition, there are large differences in measurement, calculation and analysis of the different pressure variables, as concluded by Zemp, Taylor, and Lorenzetti (2015) as well. On the other hand, variables other than seat design also affect the pressure variables, such as anthropometry and body posture. These variations between studies make it difficult to compare the studies and to conclude whether or not pressure variables are related to comfort and discomfort.

Some studies found no differences between pressure variables of different seats or cushion materials, whereas differences in comfort and discomfort perception did occur (e.g. Porter, Gyi, and Tait 2003). The main issue here is whether pressure measurements are sensitive enough to distinguish between two well-designed passenger seats. Goossens, Teeuw, and Snijders (2005) showed that, around the ischial tuberosity, humans do not notice differences of less than 1.9 kPa. In an extreme situation, pressure variables may only be a suitable measure for objectively indicating differences in comfort and discomfort between seats with very large differences in surface material or shape. Cascioli et al. (2016), for example, did find statistical differences between seats, but they were between contoured foam, straight foam and wood seat surfaces. This means that in a predictive model, pressure variables (e.g. average pressure, contact area and peak pressure) can only be used to discriminate between extremes (and only in combination with knowledge of the anthropometric data). Therefore, other variables should be incorporated in the model as well in order to predict passenger comfort and discomfort more precisely.

However, as a seat evaluation method, pressure measurements can still be used since it was also found that a pressure map could be used to predict body posture. By extension, change of body postures (movements) can also be predicted. As the number of changes (caused by fidgeting) is associated with discomfort (Na et al. 2005; Jackson et al. 2009; Le et al. 2014; Cascioli et al. 2016), a better measurement of discomfort could be the changes in interface pressure, as an indicator of fidgeting movements in time, instead of average pressure, peak pressure or contact area.

Less information was found about anthropometric variables and the effect of body postures on passenger seats. The most detailed information is available on anthropometrics and posture in relation to car driver's seats, and little information is available on tall and short people on public transport. The context of use and the seat characteristics together with anthropometrics seem to be strongly connected with the adopted posture. Detailed information for public transport specifically is lacking on this topic.

4.3. Other variables that affect passenger comfort and discomfort

The focus of this study was on specific human, seat and context variables, such as anthropometry (human), seat dimensions, shape and material (seat) and activities (context). However, other variables also affect passenger comfort and discomfort. First of all, besides physical aspects, which were selected to study in this review, mental perception is also an important factor in determining comfort (Zhang, Helander, and Drury 1996; Ahmadpour et al. 2014). Furthermore, in the aviation industry, especially exposure duration (e.g. short-haul or long-haul flight) and personal space (e.g. seat pitch) are important factors to consider when measuring comfort and discomfort.

4.3.1. Effect of exposure duration on comfort and discomfort

Some studies point out dose–response relationships between duration and comfort and discomfort. Bazley et al. (2012), for instance, found declining physical comfort levels throughout the day in offices. For the driver's seat of a car, Porter, Gyi, and Tait (2003) observed an increase in discomfort in the back, buttocks and thighs over time (after a 135-min drive). Jackson (2009) found that it took about 40 min before glider pilots started to make large fidgeting movements to relieve discomfort. Similarly, Sember (1994) concluded that it takes at least 30 min for discomfort to become sufficient for a behavioural response to occur. This is supported by Na et al. (2005), who found an increase in whole body part discomfort over time when driving a car for 45 min, as well as by Le et al. (2014), who noticed that motion occurred more often as time progressed to alleviate pressure from discomfort. Noro, Fujimaki, and Kishi (2005) showed that there is a relationship between discomfort over time in combination with seat pressure dose: the longer the duration, the greater the discomfort. According to Branton and Grayson (1967), the length of time before discomfort occurs can be increased by the design of the seat. Hence, proper seat design may reduce the increase in discomfort over time.

4.3.2. Effects of personal space on comfort and discomfort

At context level, personal space is a broad concept that includes legroom, seat pitch and cabin environment. These variables affect the perception of comfort and discomfort. For instance, Kremser et al. (2012) found that seat pitch for maximum well-being ranges from 34 to 42 inches (865–1065 mm) (corresponding legroom 32–40 inches (815–1015 mm)), depending on the passenger's anthropometry. After this maximum, the level of subjective well-being decreases. The optimal seat pitch is influenced by the passenger's buttock–knee length, and the sense of subjective well-being is influenced by the passenger's eye height. The 'ease of adopting a comfortable sitting posture' and the 'ease of changing posture', as well as the 'feeling of being restricted', the 'feeling of sitting in front of a wall' and the 'feeling of being lost', were significantly influenced by seat pitch. According to a study by Brauer (2006), the width per seat at seated eye level provided the best correlation with passenger preference for an aeroplane, which indicates that personal space is more important than total space. Row arrangements are important because passengers prefer to be seated next to an empty seat (Brauer 2006), and the chance of this happening is greater in a 3–3–3 configuration than, for example, in a 2–5–2 configuration. This indicates that a representative environment of a vehicle interior is necessary when testing seat comfort. This is supported by the findings of Ciaccia and Sznelwar (2012), which showed that participants used elements from the cabin environment to support their heads and limbs.

5. Conclusion

The aim of this review was to study the relationships between human, seat and context variables in order to predict passenger comfort and discomfort. We found that correlations do exist between anthropometric variables and interface pressure variables, and that this relationship is affected by body posture. The correlation between pressure variables and passenger comfort and discomfort has been the subject of many studies, but the results of these studies are not in line with each other due to large differences in research design. Therefore, the strength of this correlation is not clear. Hence, more research is necessary to enable a better prediction, especially in the field of passenger seat comfort and discomfort (as opposed to driver's seat comfort and discomfort), and even more variables than studied in this review have to be taken into account (e.g. personal space and exposure duration). In order to be able to build a predictive model, it is important that the relationships between the variables can be quantified. Therefore, statistical evidence is needed, such as correlation coefficients and effect sizes.

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