Universidade do Minho
Escola de Engenharia

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Adult working population anthropometrics and its application in an ergonomics context

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Doctoral Dissertation for PhD degree
in Industrial and Systems Engineering

Work done under the guidance of:
Professor Pedro M. Arezes (UMinho)
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DIREITOS DE AUTOR E CONDIÇÕES DE UTILIZAÇÃO DO TRABALHO POR TERCEIROS

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Resumo: Adult working population anthropometrics and its application in an ergonomics context

A antropometria é altamente relevante para projetar ambientes e produtos mais seguros e sustentáveis. Os dados antropométricos dos trabalhadores chilenos tinham mais de duas décadas, portanto, eles poderiam estar desatualizados principalmente devido à tendência secular. O objetivo desta tese foi estudar a antropometria da população trabalhadora chilena, abordando o crescimento secular, incorporando métodos de verificação de erros, permitindo obter informações precisas para o desenho. A metodologia pode ser dividida em duas partes. A primeira incluiu uma revisão de literatura para identificar como os levantamentos antropométricos abordavam os métodos de correção de erros. A segunda foi o trabalho de campo, onde foram recolhidas 32 medidas antropométricas de 2.946 trabalhadores. Os resultados mostram que, com exceção dos relatórios técnicos, os artigos revistos por pares abordam os métodos de teste e de erro de forma relativamente fraca, em particular no que diz respeito à identificação das fontes de erro, assim como quanto à formação dos avaliadres, aos intrumentos utilizados e à própria dimensão das amostras. Mais atenção deve ser dada aos procedimentos utilizados. As tabelas antropométricas apresentadas devem ser usadas para selecionar produtos para trabalhadores chilenos, pois evidenciam diferenças significativas quando comparadas com outras bases de dados semelhantes, reforçando a necessidade de usar dimensões específica de população. Os trabalhadores chilenos experimentaram uma tendência secular positiva, especialmente em relação ao peso e altura. As mulheres experimentaram um aumento de estatura que quase duplicou o dos homens, onde a redução da desigualdade de gênero foi associada a um menor dimorfismo da altura. Tal facto pode ser atribuído a melhores condições de vida, programas sociais e mais acesso à educação. Outras dimensões segmentares usadas no design de assentos e tarefas industriais aumentaram, reforçando a necessidade de rever destas bases de dados. A frequência do ensino superior não está mais associado a ser mais alto no Chile; portanto, outras variáveis devem ser incluídas para estabelecer o contexto socioeconômico. As recomendações para o design de cadeiras de escritório estavam desatualizadas e não incluíam novos conceitos como assentos dinâmicos, onde os padrões internacionais não produzem níveis adequados de correspondência. É necessário usar equações que considerem o sedente dinâmico, que podem ser obtidas através do uso de um assento com inclinação para frente ou cadeira de sela alta acoplada a mesas ajustáveis em altura. Pela primeira vez, são apresentadas recomendações para o desenho de postos de trabalho e tarefas a nível industrial destinadas aos trabalhadores chilenos. Os procedimentos para calcular a percentagem de *match* para uma população específica com dados resumidos demonstram ser valiosos para resolver problemas comuns de projeto. Essas recomendações de projeto devem ser em testadas no terreno, considerando medidas campo para medidas objetivas e subjetivas.
Palavras-chave: antropometria, Chile, crescimento, projeto, secular.

Abstract: Adult working population anthropometrics and its application in an ergonomics context

Anthropometrics is highly relevant as a data source for designing safer and sustainable working environments and products. Chilean workers` anthropometrics had more than 2 decades old, thus they might be outdated mainly due to secular trend. The aim of this thesis was to study the anthropometrics of Chilean adult working population addressing the secular growth incorporating error checking methods, thus allowing to have accurate information in order to design of elements, related to work systems, by considering the population specific characteristics. The methodology can be divided in two processes. The first included a literature review, which was used to identify how field anthropometric surveys addressed error proofing methods. The second one was the field work, where 32 anthropometric measures were gathered from 2,946 workers. The obtained results show that, except for technical reports, peer reviewed journals address quite poorly error testing methods in anthropometric surveys, especially when adding up other error sources, such as training of evaluators, instruments used and the dimension itself. More attention should be given to the procedures used to collect anthropometric data for ergonomics purposes. The anthropometric tables presented should be used to either produce or select products for Chilean adult workers, since they show significant differences when compared against other similar databases, thus reinforcing the need of using specific-population dimensions to design and create safer working spaces. Chileans workers have experienced a positive secular trend, especially regarding weight and height. Women have experienced a Stature increase that nearly doubled the one of men, where gender inequality reduction was associated with less sexual height dimorphism. This may be attributed to better living conditions, social programs and education access that addressed specifically women. Other segmental dimensions used in seating design and industrial tasks also increased, therefore they should be revised. Tertiary education is no longer associated with being taller in Chile, thus other variables should be included to establish the socioeconomic background of subjects. Office seating recommendations were outdated and did not include new concepts as dynamic seating, where international standards do not produce proper levels of match. New equations need to be used which consider perching as an essential component for dynamic seating, which can be obtained through the use of a forward slope seat or high saddle chair coupled with height adjustable desks. Industrial setting recommendations are provided for the first time aimed at Chilean workers. Procedures for calculating match for a specific population with summarized data prove to be of value to address common design issues. These design recommendations should be field tested for both objective and subjective measures

Keywords: anthropometrics, Chile, design, growth, secular.

Table of contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AD	Abdominal Depth
BMI	Body Mass Index
BPL	Buttock Popliteal Length
DH	Desk Height
DW	Desk Width
DHa	Desk height adjustable
DHf	Desk height fixed
EB	Elbow breadth
EHsit	Elbow Height Sitting
EHstand	Elbow height standing
EHst	Eye height standing
HW	Hip Width
KH	Knee Height
KnuH	Knuckle Height
LD	Legroom Depth
PH	Popliteal Height
S	Stature
SD	Seat Depth
SDC	Seat to Desk Clearance
SDCa	Seat to Desk Clearance fully adjustable
SH	Seat Height
SB	Shoulder breadth
SHsit	Shoulder Height Sitting
SHst	Shoulder Height Standing

SW	Seat Width
TT	Thigh thickness
TC	Thigh clearance

CHAPTER 1| Introduction and Thesis Overview

1.1. Motivation

Anthropometry is the branch of the human sciences that deals with body measurements: measurements of body size, shape, strength and working capacity (Pheasant & Steenbekkers, 2005). The characteristics of any given population will depend upon a number of factors, being the most relevant ones from an ergonomics point of view: gender, age, ethnicity and occupation (Pheasant & Steenbekkers, 2005). Other authors take anthropometric variation within a given population and attribute these variations to socioeconomic situation, which affects growth specially during the first two years of a person's life (Castellucci, Arezes, Molenbroek, & Viviani, 2015; Silventoinen, 2003; Tanner, 1992). Inadequate dimensions of products and workplaces coupled with inadequate anthropometric dimensions lead to discomfort, pain, and injuries to neck, shoulders, arms, wrist and back (Snook 1978, Wichansky 2000, Pentikis et al., 2002). Musculoskeletal disorders (MSD´s) due to the mismatch between products and anthropometrics have been found in different contexts such as: office environments (Sundelin and Hagberg, 1989), assembly lines (Schuldt, 1988) and in the transport sector (Hedberg, 1987). Work-related MSD's are the costliest health problems today (National Research Council, 2001). Controlling these disorders is complex and therefore a preventive approach is always the best, since symptomatic onset is unclear and cumulative exposure is responsible for its occurrence (Dempsey, 2007). The criteria that define a successful outcome to the design process falls into three main groups: comfort, performance, and health and safety. These three factors together benefit the companies' productivity and efficiency (Pheasant & Steenbekkers, 2005). Currently, anthropometry is considered as an important factor for the prevention of several work-related problems. This matter is being addressed by specific international technical standards (ISO, 2008, 2010a, 2010b, 2012a, 2013) and other technical standards that take into account anthropometry for prevention of diseases and accidents (ISO, 2000, 2002, 2003). Additionally, there are even standards for specific industrial sectors like control rooms (ISO, 2011) and healthcare (ISO, 2012b).

Anthropometry is very sensitive to measurement error (Villamor & Bosch, 2014). To avoid the variability of the measures and reduce measurement error, the World Health Organization's propose the following quality assurance measures (WHO, 2006): (i) standardized data collection methodology, (ii) rigorous training and monitoring of data collection personnel, (iii) frequent and effective equipment calibration and maintenance, and (iv) periodic assessment of anthropometric measurement reliability Furthermore, the International Standard Organization (ISO) developed some standards (ISO, 2008, 2010, 2013) that provide a description of anthropometric measurements which can serve as a guide for ergonomists to make possible comparisons between international population segments.

There are several large anthropometry databases, some of the most relevant ones being mentioned in ISO (2010b), such as the CAESAR database that considered US and European populations (Harrison & Robinette, 2002; Robinette et al., 2002). Furthermore, ISO (2010b) also includes databases from other countries like Japan, Korea, Thailand, Italy, and Kenya. All the databases presented in ISO 7250-2 collected anthropometric measurements with either just manual techniques (Thailand, Germany, Italy, Japan, Kenya, Korea), with 3D scans (US), or both techniques (Netherlands). Another highly relevant large sources of anthropometric data are the ANSUR, MC- ANSUR and ANSUR II surveys, where military personnel were measured (Gordon et al., 1988; 2012; 2013). Likewise, NASA has collected large amounts of data, for their interspace shuttle designs (NASA, 1978) and even for specific sectors such as truck drivers (Guan et al., 2012; 2015). Similar research efforts have also produced large anthropometric databases using civilians from other countries, such as Korea (Korean Agency for Technology and Standards, 2004) and Japan (Research Institute of Human Engineering for Quality Life, 2007). In general, all of these databases are updated as needed in order to account for secular trend and other specific needs, like addressing military personnel like the ANSUR surveys, where one of them Specifically MC-ANSUR, was made to address US Marines anthropometry.

In the case of Chile, for example, the anthropometric tables of Chilean workers developed by Apud & Gutierrez (1997) are the current available information source where Chilean designers can have access to data needed to design products, clothing tools and working spaces. These tables however only considered certain working groups (fire brigade workers, mining workers and salmon industry workers) and Chilean country regions. Furthermore, the use of these tables may be affected by secular trend, which is the growth observed in populations and that it has been defined as an increase in average height among same age individuals in successive generations (Arcaleni, 2006; Cole, 2000, 2003; Tanner, 1986, 1992). This positive secular trend has been observed in several countries, with an average growth between 0.7 cm and 4 cm per decade (Fredriks et al., 2000), and specifically in Chile, It has also been observed in Chilean school children (Castellucci et al., 2015; Gutiérrez & Apud, 1992). In general, this trend is assumed to occur as a result of a change in environmental conditions, in particular by eliminating factors that block the full expression of biological potential, such as infectious diseases, inadequate nutrition, poverty and disease in general (Arcaleni, 2006; Cole, 2000, 2003; Tanner, 1986, 1992), thus, population growth can be assumed as a "mirror of conditions in society" (Tanner, 1986), where a positive secular trend is assumed to reflect changes in living standards and dietary habits (Hauspie et al., 1996; Silventoinen, 2003).

In the scope of this work, a positive secular trend is a very important factor to take into account since the anthropometric data of the tables correspond to 1997, which may indicate that the data may be outdated, since they are practically two decades old. The previous situation does not allow incorporating any preventive design recommendations in Chilean technical guidelines in an accurate way. For instance, the "Guía Técnica para la evaluación y control de los riesgos asociados al manejo o manipulación manual de carga" (Ministerio del Trabajo y Previsión Social, 2008) elaborated by the Chilean Work Ministry, provides rather vague recommendations for production lines heights where standing manual handling tasks are done, safe storage heights and handle locations for pulling and pushing tasks. In this guideline, reference to a specific anthropometric dimension is made, not providing specific values. For example, for designing the height of a production line where manual handling is performed, the recommendation of the guide in page 114 says: "In general the optimum height of the work surface for standing manual handling should be the one of elbow height standing…for light and heavy manual handling, the recommended height should be lower than elbow height standing. For precision tasks standing, the height should be above the elbow height standing, in order to allow elbow support for precise manual and visual control." As it can be seen these recommendations leads open to interpretation, thus more likely to provide a design not suited for the target population.

Currently, the outdated anthropometrics tables for the Chilean working adult population present a great problem, since the new designs of work and leisure spaces and the controls in the field of prevention are based on erroneous data, which is why it is necessary to raise new data on the Chilean working population (Hanson et al., 2009).

1.2. Objectives

The main objective of the current research is to characterize the anthropometrics of Chilean adult working population addressing the secular growth incorporating error checking methods, which will allow facilitating the design of elements, related to work systems, by considering the population specific characteristics.

In order to achieve the defined general goals, the following more specific objectives were also considered:

1. Determine the most common error prevention and testing methodologies used in published peer reviewed journals
2. Anthropometric characterization of Chilean adult working population.
3. Apply error-testing formulas to data collected in this project and analyze its suitability.
4. Determine the presence of secular growth in the Chilean working population.
5. Determine how suitable to Chilean population common design calculations in ergonomics using anthropometrics are
6. Application of anthropometrics of Chilean workers in preventive industrial design recommendations

1.3. Thesis Synopsis

The current thesis is structured in a series of Chapters, namely chapters 1 to 9. The first chapter is an introduction justifying the research done. The last chapter is a conclusion of the main findings and also provides further research suggestions. The remaining chapters (chapters 2 -8) detail the different and specific studies performed. Thus, the structure of the thesis is:

- Chapter 1: Introduction
- Chapter 2: Review: Accuracy, Precision and Reliability of adult working population
- Chapter 3: Anthropometric characteristics of Chilean workers for ergonomic and design purposes
- Chapter 4: Educational level and its relationship with body height and popliteal height in Chilean male workers
- Chapter 5: Secular changes in the anthropometrics of Chilean workers and its implicance in design
- Chapter 6: Gender inequality and height sexual dimorphism in Chile
- Chapter 7: Application of mismatch equations to dynamic office seating designs
- Chapter 8: Applied anthropometrics for common industrial settings design: working and ideal manual handling heights
- Chapter 9: Conclusions and future work

Most of the chapters of this thesis, namely those from 2 to 8 consist of a compilation of studies that were also developed as scientific papers, which seek to accomplish with the research objectives previously defined. Although almost all the papers were already published (or submitted in its final format) and are presented here as they were publsihed, some of them had been changed in this thesis as some minor errors were identified later, namely some small typographical or grammatical errors. The “status” of each paper is indicated in the beginning of each chapter.

Additionally, the thesis has also two more chapters, one in the beginning and one at the end, as described in the following paragraphs.

Chapter 1 is an introduction to the subject and to the thesis and where it is presented the context and motivation of this work, as well as its objectives.

Chapter 2 is a systematic review focused on a very important issues regarding anthropometric surveys. It gives an overall picture of how peer reviewed literature considers and manages measurement error in the context of anthropometric surveys in adult working populations. Considering the bibliography published, the study tried to clarify how different authors define common error control terminologies, as well as different mechanism to test them. Chapter 2 additionally goes further to discuss common sources of error and provides recommendations to keep them under control.

Chapter 3 corresponds to the second study performed, entitled " Anthropometric characteristics of Chilean workers for ergonomic and design purposes". This study presents the updated anthropometric dimensions of Chilean adult working population for both males and females. It presents also the implications for the design of spaces and products. This paper is the result of the field work and applies the methods for error measurement prevention discussed in Chapter 2. The reader may notice that the original thesis plan was modified, since originally Chapter 2 was aimed at the "Application of formulas and suitability comparisons of accuracy, precision and reliability". This was done because due to the practical or ecological nature of an anthropometric survey, it was deemed appropriate by the research team and Phd supervisors to include in this chapter the results of the methods defined previously as the best to control error during practice and execution of the measurements by multisite teams.

Chapter 4 presents a third study “Educational level and its relationship with body height and popliteal height in Chilean male workers”. Emerged from the analysis of the data since for the first time in Chile, anthropometric dimensions were associated with the age and educational level of the subjects. This chapter considers the impact on two anthropometric of attaining incremental levels of educations by different birth cohorts, trying to address possible causes that might have caused the changes reported.

Chapter 5 corresponds to the fourth study " Secular changes in the anthropometrics of Chilean workers and its implicance in design", where the secular trend of the anthropometric dimensions gathered was obtained comparing the data from the sample against data from 1995. Additionally, comparisons with other similar databases and implications of secular trend in design are discussed.

Chapter 6 entitled "Gender inequality and height sexual dimorphism in Chile" emerged when analysing the data for secular trend. It was observed that females nearly doubled males in the observed period. This chapter had the ambition to analyse how improvement in overall living conditions and specifically regarding gender equality have influenced the secular growth of females.

In chapter 7, which was entitled " Application of mismatch equations to dynamic office seating designs", the entire sample was used to analyse how the use of the national and one international office furniture standards would impact in the level mismatch considering traditional, adjustable, and dynamic seating. Additionally, proposals are made for the sample under questions discussing newly proposed equations for obtaining dynamic seating.

Chapter 8, entitled "Applied anthropometrics for common industrial settings design: working and ideal manual handling heights“, similarly to chapter 7, provides the first ever dimensional requirements aimed at Chilean workers for designing industrial settings heights for assembly tasks according to task type and ideal manual handling heights and depths. The levels of match for the sample when applying both univariate and bivariate method are presented also with methods and examples on how they can be used in common ergonomics/design problems.

Finally, chapter 9 summarizes the carried out work and the main conclusions obtained at the different studies and suggests possible directions for future work in this specific domain.

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CHAPTER 2| Accuracy, precision and reliability in anthropometric surveys for ergonomics purposes in adult working populations: A literature review

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Anthropometric surveys are the most common method of gathering human morphometric data, used to design clothing, products and workspaces. The aim of this paper was to assess how current peer reviewed literature addresses the accuracy, reliability and precision regarding manual anthropometric surveys applied to adult working populations in the field of ergonomics. A literature review was performed in two electronic databases for finding relevant papers. A total of 312 papers were reviewed, of which 79 met the inclusion criteria. The results shown that the subjects of these publications are poorly addressed, so that only 27 studies mentioned at least one of the terms and none of the studies evaluated all of the terms. Only one paper mentioned and assessed precision and reliability of the measurement procedure. Furthermore, none of the publications evaluated accuracy. Moreover, the reviewed papers presented large differences in the factors that affect precision, reliability and accuracy. This was particularly clear in the measurer technique/training, measurement tools, subject posture and clothing. Researchers in this area should take more rigorous approaches and explicit indicators with their results should be presented in any report. Relevance for industry: It is important that scientific literature related to manual anthropometric measurements uses methods for assessing measurement error, since these data are often used to design clothing and workspaces as well as to calibrate non-manual methods such as 3D scanners.

2.1. Introduction

Anthropometry is the branch of the human sciences that deals with body measurements: measurements of body size, shape, strength and working capacity (Pheasant & Steenbekkers, 2005). The characteristics of any given population will depend upon a number of factors, of which the most relevant ones from an ergonomics point of view are: gender, age, ethnicity and occupation (Pheasant & Steenbekkers, 2005). All of these aspects must be considered in order to match the designs of products, environments and systems, as a whole. The physical characteristics of target users (Garneau & Parkinson, 2016) have to be considered to allow the workplaces and products to be suited to the workers' body size and motion (Kroemer & Grandjean, 1997). The criteria that define a successful outcome to the design process falls into three main groups: comfort, performance, and health and safety. These three factors together benefit the companies' productivity and efficiency (Pheasant & Steenbekkers, 2005).

Currently, anthropometry is considered as an important factor for the prevention of several work-related problems. This matter is being addressed by specific international technical standards (ISO, 2008, 2010a, 2010b, 2013) and other technical standards that take into account anthropometry for prevention of diseases and accidents (ISO, 2000, 2002, 2003). Additionally, there are even standards for specific industrial sectors like control rooms (ISO, 2011) and healthcare (ISO, 2012a). There are several large anthropometry databases, some of the most relevant ones being mentioned in ISO (2010b), such as the CAESAR database that considered US and European populations (Harrison & Robinette, 2002; Robinette et al., 2002). Furthermore, ISO (2010b) also includes databases from other countries like Japan, Korea, Thailand, Italy, Kenya. All the databases presented in ISO 7250-2 collected anthropometric measurements with either just manual techniques (Thailand, Germany, Italy, Japan, Kenya, Korea), with 3D scans (US), or both techniques (Netherlands). Other highly relevant large sources of anthropometric data are the ANSUR, MC-ANSUR and ANSUR II surveys, where military personnel were measured (Gordon et al., 1988; 2012; 2013). Likewise, NASA has collected large amounts of data, for their interspace shuttle designs (NASA, 1978) and even for specific sectors such as truck drivers (Guan et al., 2015).

Similar research efforts have also produced large anthropometric databases using civilians of other countries such as Korea (Korean Agency for Technology and Standards, 2004) and Japan (Research Institute of Human Engineering for Quality Life, 2007).

Manual measurements of anthropometric characteristics are commonly used due to their main benefits: relatively low cost compared to more automated equipment like 3D scans; ease of measurements and the need for less complex equipment. However, manual anthropometric techniques can present issues related to human measurement errors (Sicotte et al., 2010). When anthropometrical measures are repeated the two sources of variation are: biological variation of individuals – that cannot be avoided – and technical variations – that can be avoided. The variability on the anthropometrical measurements caused by variations on the technique execution is responsible for a higher incidence of error (Perini et al., 2005).

Anthropometry is very sensitive to measurement error (Villamor & Bosch, 2014). To avoid the variability of the measures and reduce measurement error, the World Health Organization proposed the following quality assurance measures (WHO, 2006): (i) standardized data collection methodology, (ii) rigorous training and monitoring of data collection personnel, (iii) frequent and effective equipment calibration and maintenance, and (iv) periodic assessment of anthropometric measurement reliability. Furthermore, the International Standard Organization (ISO) developed some standards (ISO, 2008, 2013) that provide a description of anthropometric measurements which can serve as a guide for ergonomists to make possible comparisons between international population segments.

Published scientific literature use several terms to define anthropometric measurement error. Regardless of the terms used, the effects of measurement error can be mainly categorized depending by the extent to which the repeated measures give the same value or the extent to which a measure departs from the true value (Ulijaszek & Kerr, 1999).

2.1.1. Repeated Measures: precision and reliability

While there are several definitions of precision and reliability in the published literature (Habicht et al., 1979; Heymsfield et al., 1984; Mueller & Martorell, 1988;

Norton & Olds, 1996; Ulijaszek & Kerr, 1999; Wong et al., 2008), they may confuse readers since they are very similar, thus, for the purposes of this paper, we defined the precision according to Norton and Olds (1996). Precision is a characteristic of a specific measurer executing a specific measurement technique on a specific body dimension (Norton & Olds, 1996). Reliability has the same features plus being dependent on the individual differences (Norton & Olds, 1996). These individual differences are grouped by dependability term. Dependability is a function of physiological variation, such as biological factors, that can modify the reproducibility of the measure, even if the technique does not vary (Sicotte et al., 2010; Ulijaszek & Kerr, 1999). One example of dependability is the variation of stature in the same subject, between hours of the day, despite of the technique used to take it, as stature decreases throughout the day (Tillmann, 2001). Since reliability is usually measured using coefficients, its indicators will be, in general, more correlated in highly heterogeneous subjects than for a group of more similar ones (Pederson & Gore, 1996). Another difference is that precision measurements may be used in subsequent calculations (i.e. confidence intervals, sample size), while measures of reliability, conversely, are just technique indicators and should not be used for further calculations (Pederson & Gore, 1996). According to Pederson and Gore (1996) precision is the most basic indicator of an anthropometrist's expertise or ability. When the levels of precision are quoted in a technical report, the readers should be given both the results and the acceptable standards in order to assess the precision of each variable (Norton & Olds, 1996). For example, according to the International Society for the Advancement of Kinanthropometry (ISAK), some anthropometric dimensions like skinfolds, should have an accepted precision measured in mm, depending on the skinfold taken (Norton & Olds, 1996). Precision levels for several body measurements can be found in Gordon et al. (1988; 2012) and other technical reports that researchers can use in order to establish a baseline. Regarding other differences between precision and reliability, Bruton et al. (2000) state that reliability is related to the repeatability or consistency of measurements, measurers or instruments, and it is usually assumed that the reliability of a measurement relies on precision and dependability, where the former being the most important determinant (Mueller & Martorell, 1988). Finally, it is important to mention that precision and reliability evaluation can be performed to evaluate repeated measurers in two situations e.g.:

single measurer in two or more different times (intra-measurer) or two or more measurers (inter-measurers).

2.1.2. True value: accuracy

Accuracy refers to the closeness of the measurements to some reference or standard value accepted as the ‘truth’ and expresses a relation to a value external to the measurement process (Roebuck et al., 1975). In anthropometry, accuracy is related to the “gold standard” which is used to compare the results of new anthropometrists against expert anthropometrists (Norton & Olds, 1996). In general, true values are complicated to identify in anthropometrics. However, those values are usually determined by comparing experienced measurers results against the research team, until a certain standard is achieved (Gordon et al.1988; Norton & Olds, 1996). Despite that, in practice this would imply that throughout the project the results obtained by the research team should be systematically compared against a gold standard, which may be very time consuming and expensive to achieve, since at least a sample of subjects should be re-measured by the experts in order to assess accuracy. Roebuck et al. (1975) mention that accuracy is generally best approximated by the use of precisely calibrated, rigid instruments carefully positioned by trained investigators under controlled environmental conditions. This statement implies that the best a research team can do is trying to be the closest to the true value, since the difficulties inherent to measure humans is a major obstacle to obtain a true value, as Pheasant & Halsegrave (2006) have pointed out: “The human body has very few sharp edges—its contours are rounded and it is generally squashy and unstable”, thus generally it must be admitted that ‘true’ values are very difficult to obtain or calculate (Ulijaszek & Kerr, 1999).

This research study, carried out mainly through a literature review, sought to answer the following research question: ‘Did the currently existing anthropometric studies published only in peer reviewed journals of adult working populations, related to ergonomics, mentioned and/or evaluated precision, reliability or accuracy of the measurement methods and data collected?

2.2. Method

In order to properly answer the research question, a Literature Review was used (Tranfield, Denyer, & Smart, 2003). This methodology, besides being replicable and scientifically transparent, it is also very useful to generate a basic framework for an in-depth analysis of the existing literature (Tranfield et al., 2003).

Two databases, SciVerse Scopus and PubMed, were used for finding relevant papers published in the field studies of anthropometric surveys for ergonomics purposes involving adult working population.

Regarding the search criteria, the search terms used were: 'anthropometric characteristics', 'anthropometric dimensions' and 'anthropometric measures'. To avoid papers not falling into the topic under study, the search was performed using the Boolean operator ''AND'', together with the search term 'ergonomics'. The following combination were used: 'anthropometric characteristics' AND 'ergonomics'; 'anthropometric dimensions' AND 'ergonomics'; 'anthropometric measures' AND 'ergonomics'.

Apart from the criteria mentioned above, the following additional inclusion criteria were also adopted:

- Original and review articles written in English published, or in press, in peer-reviewed journals;
- Published or in press between January 1990 and June 2016;
- Papers that considered the evaluation of anthropometric measures by using manual methods;
- Papers with an ergonomics research/application purpose;
- Papers that focused on describing the execution of manual anthropometric surveys in order to establish a database;
- Papers with adult samples, with ages between 18 and 65 years old. Studies were also considered and included if part of the study sample fell in the selected age range. Samples that included adult college/university students were also included.

Studies that merely presented anthropometric measures with focus in nutritional status, body composition or sports performance (e.g. stature, weight, body mass index, skinfolds, hip and waist circumference) were excluded. Examples of exclusions are Salamat et al. (2015), Sett & Sahu (2016) and Gabbett (2005). Studies that presented exclusively 3D or photography methods to collected data were also excluded, such as the examples of the works from Barroso et al. (2005) and Coblentz et al. (1991). In cases where manual methods where used together with other 3D methods or digitizing arms, the paper was included, and that was the case of the paper by Hsiao et al. (2014). Exclusion was also applied to studies that aimed to validate another anthropometric survey method using traditional methods (Li et al., 2008; Meunier & Yin, 2000). Studies that focused only on school children (Castellucci et al., 2015) or children only (Stone et al., 2013) were also excluded. Although some papers did use working adults anthropometric data in an ergonomics context, they were not considered since they used some already available anthropometric databases and did not take any manual measurement, thus based their findings in previously executed surveys or technical reports (e.g., Hong et al., 2014; Mavrikios et al., 2006; Snook & Ciriello, 1991; Van Veelen et al., 2003). Studies that only used special populations, such as wheel chair/disabled subjects (Kozey & Das, 2004), elderly (Dawal et al., 2015) and pregnant women (Wu et al., 2015) were also excluded.

Before starting the results and discussion process and to avoid misunderstandings, the terms/variables (e.g. accuracy, precision, reliability and their synonymous) were considered to be evaluated when an equation or formula was applied and the results were presented. Another alternative for consideration of a particular term was when there was a clear mentioning of the analysis for that term/variable. There were some cases where the terms were mentioned without any evaluation, like the study of Chavalitsakulchai and Shahnavaz (1993): “the accuracy of the measurements was checked and confirmed by rechecking measurements three times for each subject”. In these cases, although the accuracy was mentioned, it was not considered to be evaluated since neither formula nor results were presented (Table 2.1). Also, in the study of Chavalitsakulchai and Shahnavaz (1993) is important to notice that accuracy was not considered as “true value” but as repeated measures, which is conceptually wrong.

Titles and abstracts were checked separately by two of the authors in order to select relevant papers that were later analyzed for their full text. If any paper seemed suitable but the abstract was not available, then the full text was downloaded. Discrepancies among authors were referred to the others three authors, in order to perform joint discussion of the publication; thus the particular publication was included or excluded. Two authors using a standardized data extraction form reviewed full versions independently, and disagreements between them were referred to the other authors. Primary studies meeting the inclusion criteria were identified and the corresponding relevant information required was analyzed.

2.3. Results and Discussion

Figure 2.1 shows the results of the search strategy. The search on the databases resulted in an initial number of 541 papers (SCOPUS: 363 and Pubmed: 178), which was then reduced to 312 after the removal of duplicate entries. After screening the title, abstract and keywords of each article, 247 papers were identified as being potentially relevant. Additionally, when trying to access and download the articles, nine of them were not available. After reviewing the corresponding full-texts, 79 papers were selected on the basis of the inclusion criteria.

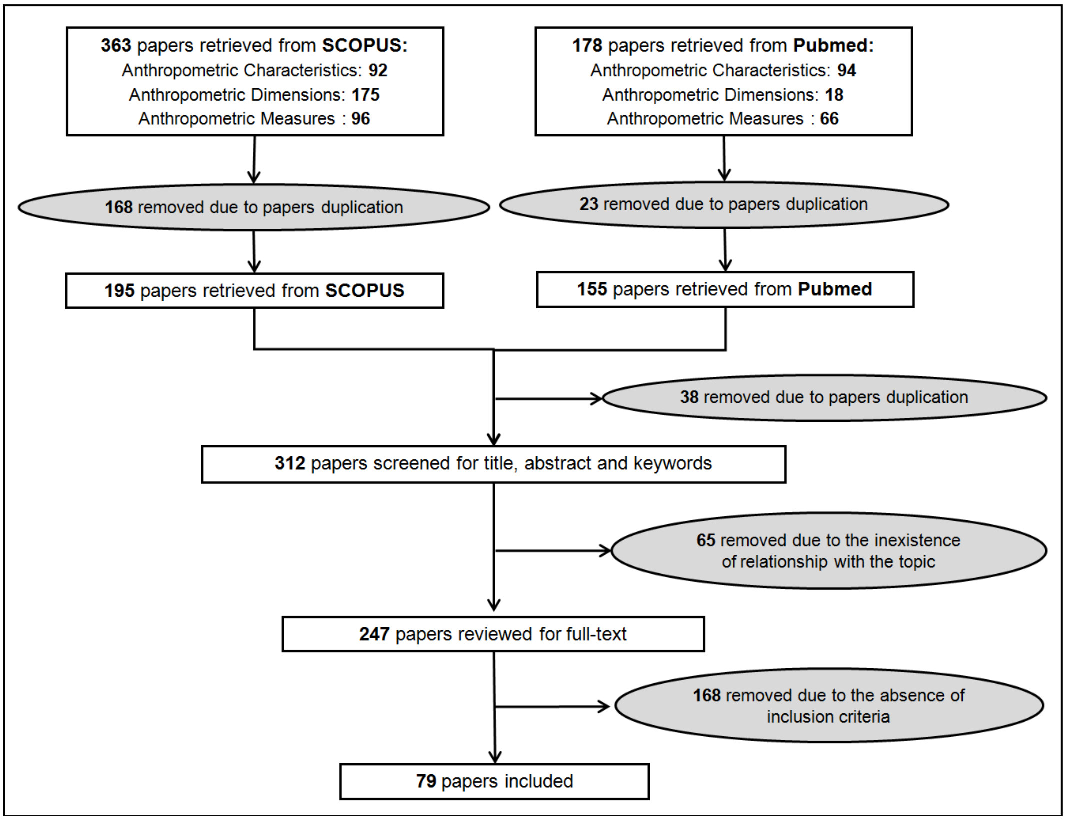

Figure 2.1. Diagram of the used search strategy

2.3.1. True value: Accuracy

The results from Table 2.1 show that nine out of the 79 studies mentioned the word accuracy but none of them evaluated it. Other five authors mentioned accuracy but it was related to the instrument accuracy, not the measurement procedure (Eksioglu, 2016; Hanson et al., 2009; Khadem & Islam 2014; Mahmoudi & Bazrafshan, 2013; Mousavifard & Alvandian, 2011). It is important to point out that this study did not consider the accuracy related to a gold standard, as defined on this review, thus accuracy was used here to illustrate that the used instruments were the appropriate ones. Some of the authors mentioned that accuracy of measurements was achieved by practicing prior to the data collection sessions or that it was achieved by taking more than one time and using the average value, for example the papers from Chavalitsakulchai and Shahnavaz, (1993) and Ismaila et al. (2013). This assumption is far from being correct, since the average value may not be necessarily accurate, for example one can take 3 measurements of wrist breadth for a particular subject and getting an average value that was not even measured (e.g.: (7 cm + 6 cm + 6 cm) / 3 = 6,3 cm). Therefore, it is difficult to state that using this procedure of averaging 3 measurements will, in fact, assure getting accurate or true measures (Pheasant & Haslegrave, 2006). Furthermore, most authors declared that the accuracy of the measurements was achieved by undergoing training and supervision, such as the papers by Ismaila et al. (2013) and Pourtaghi et al. (2014). In some way, the presented results of achieved accuracy could be supported by the ISO 15535 (ISO, 2012c), in which it is mentioned that "frequent and regular measurer training and quality control shall be carried out by persons experienced in anthropometry, in order to ensure acceptable standards of accuracy".

However, there are some issues that need to be addressed, considering that inaccuracy is a systematic bias, and could be associated with instrument or technique error (Ulijaszek & Kerr, 1999):

a) **Instruments:** considering the recommendation from ISO 7250-1 (ISO, 2008), nine of the 79 studies that mentioned accuracy, used the recommended instruments (anthropometer or sliding calliper) for data collection in the studies. However, only four specified both the type and brand, where the remaining five did not specified the brand (Table 2.2). On the other hand, some authors, used plastic tape (Hanson et al., 2009), steel measuring tape (Sadeghi et al., 2015) or retractable tape (Bello & Sepenu, 2013) to collect linear distances, such as foot breadth, hip breadth and popliteal height, which may affect the level of accuracy (Table 2.2). Other authors, such as Cai & Chen (2016), did not specify the type of instruments used for taking a particular set of measures (Table 2.2). Five studies mentioned accuracy in relation to the instruments, but not the procedure of measurement itself (see Table 2.2). Among these, two studies mentioned that equipment was calibrated or tested for accuracy, but did not present any indicators or results that shows that it was the actual measurement procedure that was under assessment and not the instruments (Eksioglu, 2016; Mahmoudi, 2013); two other studies mentioned that the equipment was also accurate did not present results or indicators for accuracy (Khadem & Islam, 2014;

Mousavifard & Alvandian, 2011) and finally only one study has mentioned unit accuracy levels (i.e., the accuracy levels for the measuring tape was of 2mm) (Hanson et al., 2009) but did not present any equation or procedure adopted to determine that specific value that might have helped to know if the measurement procedure was under assessment. Instrument accuracy is an important issue that is related to the observer accuracy, and though it was a concern for many authors, this issue was poorly addressed in the reviewed papers. A deeper analysis of the measurement tools used is presented in section 3.3.2.

b) **Measurement technique:** assuming that the studies used a measurer that was experienced in anthropometry, without applying any equation or formula it is very difficult to calculate the differences between the expert anthropometrists (considered as "true value") with the new measurers. One solution to prove the level of accuracy was developed by the International Society for the Advancement of Kinanthropometry (ISAK), which use the Technical Error of Measurement (TEM) as an evaluation index to the accreditation of new anthropometrists (Geeta et al., 2009; Perini et al., 2005). The TEM is basically the square root of measurement error variance (Arroyo et al., 2010), and is used to compare the results of the new anthropometrists against the expert anthropometrists (ISAK level 3 or 4). It is important to mention that despite the fact that ISAK, in levels 2 and 3, considers teaching anthropometry as an option in the ergonomics field (Norton & Olds, 1996), it does not consider the same measurements normally applied in the field of ergonomics stated in ISO 7250-1 (ISO, 2008). For example, they only included certain lengths and breadths and overlooked other dimensions, such as popliteal height and elbow height, both of which are critical for workplace design that might be not fully covered by ISAK`s gold standards (Kroemer & Grandjean, 1997; Pheasant & Haslegrave, 2006).

Table 2.1. Summary of the studies referring to accuracy, precision or reliability

Author and year	Sample	Term					
		Accuracy		Reliability		Precision	
		M	E	M	E	M	E
Ademola et al., 2014	N=288, between 18 and 25 years old.	X	X	X	X	X	X
Akhter et al., 2009	N=100, between 25 and 45 years old.	X	X	X	X	X	X
Bello & Sepenu, 2013	N=126, between 25 and 35 years old.	X	X	X	X	X	X
Bylund & Burstrom, 2006	N=40, between 20 and 23 years old.	X	X	X	X	X	X
Cais & Chen, 2016	N=40, between 20 and 60 years old.	X	X	X	X	X	X
Castilho et al., 2012	N=745, average age 23.04 years old (ages N/S).	X	X	X	X	X	X
Cengiz, 2014	N=225, between 18 and 65+ year old.	X	X	X	X	X	X
Chavalitsakulchai & Shahnavaz, 1993	N=200, between 18 and 39 years old.	✓	X	X	X	X	X
Chi et al., 2012	N=24, between 19 and 34 years old.	X	X	X	X	X	X
Chuang et al., 1997	N=120, between 16 and 20 years old.	X	X	X	X	X	X
Dawal et al., 2012	N=143, average age 22.6 years old (ages N/S).	X	X	✓	✓	X	X
Deros et al., 2011	N=20 male assembly workers (ages N/S).	X	X	X	X	X	X
Deros et al., 2009	N=638, between 18 and 80 years old.	X	X	X	X	X	X
Dewangan et al., 2010	N=801, between 18 and 60 years old.	✓	X	X	X	X	X
Dhara et al., 2016	N=78, between 18 and 50 years old.	X	X	X	X	X	X
Du et al., 2008	N=3000, between 18 and 66 years old.	✓	X	X	✓	X	X
Eksioglu, 2016	N=211, between 18 and 69 years old.	✓*	X	X	X	X	X
Flyte & Perchard., 1999	N=97, between 18 and 65+ years old.	X	X	X	X	X	X

Genaidy et al., 1995	N=28, average age 26 years old (ages N/S).	X	X	X	X	X	X
Gil et al., 1998	N=30, between 19 and 26 years old.	X	X	X	X	X	X
Guan et al.,2012	N=1950, between 20 and 55 years old.	X	X	X	X	X	✓
Gunther et al., 2008	N=769, between 20 and 95 years old.	X	X	X	X	X	X
Hanson et al., 2009	N=367, between 18 and 65 years old.	✓*	✓*	X	X	X	X
Hoque et al., 2014	N=500, between 17 and 22 years old.	X	X	X	X	X	X
Hsiao et al., 2005	N=94, between 18 and 76 years old.	X	X	X	X	X	X
Hsiao et al., 2014	N=951, between 18 and 65 years old.	X	X	X	X	X	X
Imrhan & Sundararajan,1992	N=36, between 22 and 44 years old.	X	X	X	X	X	X
Imrhan et al., 2009	N=101, between 25 and 58 years old.	X	X	X	X	X	X
Ismaila et al., 2013	N=720, between 17 and 27 years old.	✓	X	✓	X	X	X
Karmegan et al., 2011	N=300, between 18 and 24 years old.	X	X	X	X	X	X
Kawahara et al., 1998	N=30, average age 68.1 years old. (ages N/S)	X	X	X	X	X	X
Khadem & Islam 2014	N=470, between 15 and 64 years old.	✓*	X	✓	X	X	X
Kumar & Garand, 1992	N=30, between 18 and 28 years old.	X	X	X	X	X	X
Laing et al., 1999	N=691, between 37.4 and 64.4 years old.	X	X	✓	✓	X	X
Lavender et al., 2002	N=87, between 16 and 40 years old.	X	X	✓	X	X	X
Lee et al., 2013	N=862, between 15 and 82 years old.	X	X	X	X	✓	✓
Lucero et al., 2012	N=2900, average age 30.24 years old female and 33.51 years old male. (ages N/S)	X	X	X	X	X	X
Mahmoudi & Bazrafshan, 2013	N=47, between 18 and 48 years old.	✓*	X	X	X	X	X
Mahoney et al., 2015	N=21 college students (ages N/S)	X	X	X	X	X	X
Marklin et al., 2010	N=187, between 22 and 44 years old.	X	X	✓	✓	✓	✓
Matias et al., 1998	N=100 VDT operators. (ages N/S)	X	X	X	X	X	X

Mazloumi & Mohammadreze, 2012	N=30 male Iranian drivers. (ages N/S)	X	X	X	X	X	X
Mohamed Thariq et al., 2010	N=385, between 20 and 28 years old.	X	X	X	X	X	X
Mokdad, 2002	N=514, between 15 and 75 years old.	X	X	✓	X	X	X
Mousavifard & Alvandian, 2011	N=256, between 15 and 65+ years old.	✓*	X	X	X	X	X
Nag et al., 2003	N=95, between 16 and 58 years old.	X	X	X	X	X	X
Nicolay & Walter, 2005	N=51, between 18 and 33 years old.	X	X	X	X	X	X
Oñate et al., 2012	N=447, average age 38.9 years old. (ages N/S)	X	X	X	X	X	X
Osquei-Zadeh et al., 2012	N=267, between 18 and 26 years old.	X	X	X	X	X	X
Pennathur & Dowling 2003	N=not specified, between 20 and 85 years old.	X	X	X	X	X	X
Pourtaghi et al., 2014	N=12635, between 18 and 30 years old.	✓	X	✓	✓	X	X
Reis et al., 2012	N=200, average age 33.5 years old female and 35.7 years old male.	X	X	X	X	X	X
Sadeghi et al., 2014	N=3436, between 20 and 60 years old.	✓	X	✓	X	X	X
Sadeghi et al., 2015	N=3720, between 20 and 60 years old.	✓	X	✓	X	X	X
Shah et al., 2015	N=200, between 25 and 45 years old.	X	X	X	X	X	X
Shrestha et al., 2009	N=444, between 25 and 50 years old.	X	X	X	X	X	X
Simeonov et al., 2012	N=40, average age 42.7and 37.2 years old. (ages N/S)	X	X	X	X	X	X
Singh et al., 2015	N=940, between 20 and 60 years old.	X	X	X	X	X	X
Spasojević et al., 2015	N=64,average age 47.64 years old. (ages N/S)	X	X	X	X	✓	X
Stålhammar & Louhevaara, 1992	N=18, average age 33.8 years old. (ages N/S)	X	X	X	X	X	X
Sudhakaran & Mirka, 2005	N=24, between 18 and 26 years old.	X	X	X	X	X	X
Sutjana et al., 2008	N=124, between 18 and 23 years old	X	X	X	X	X	X
Syuaib, 2015a	N=141 palm oil male workers (ages N/S)	X	X	X	X	X	X

Syuaib, 2015b	N=371, average age 39,3 years old female and 43,7 years old male. (ages N/S)	✓	X	X	X	X	X
Taha et al., 2009	N=887, between 20 and 30 years old	X	X	X	X	X	X
Toro & Henrich, 1997	N=281 puerto rican workers , (ages N/S)	X	X	X	X	X	X
Tunay & Melemez, 2008	N=1049 university students, (ages N/S)	X	X	X	X	X	X
Ugurlu & Ozdogan, 2011	N=770, between 18 and 25 years old	X	X	X	X	X	X
Van Driel et al., 2013	N=8, between 18 and 28 years old	X	X	X	X	X	X
Verhaert et al., 2011	N=17, average age 24.3 years old (ages N/S)	X	X	X	X	X	X
Wang & Chao, 2010	N=30, between 18 and 60 years old	X	X	X	X	X	X
Werner et al., 1998	N=727, between 25 and 69 years old	X	X	X	X	X	X
Wibowo et al., 2013	N=321 indonesian farmers, (ages N/S)	X	X	X	X	X	X
Widyanti et al., 2015	N=1133 university students, (ages N/S)	X	X	✓	X	✓	X
Xiong et al., 2008	N=50, between 19 and 24 years old	X	X	✓	✓	X	X
Yang et al., 2007	N=461, between 23 and 43 years old	✓	X	✓	X	X	X
Yun et al., 2002	N=8 college students, (ages N/S)	X	X	X	X	X	X
Zetterberg & Ofverholm, 1999	N=564, between 20 and 61 years old	X	X	✓	X	X	X
Zujnic et al., 2015	N=64 crane operators, average age 46.6 years old (ages N/S)	X	X	X	X	X	X

M: mentioned; E: evaluated. * Accuracy related to the measurements tools.

2.3.2. Repeated Measures: Precision and Reliability

The evaluation of the precision and reliability should be considered in every study as a direct indicator of data quality. Also, a reduced number of errors in measurements will increase the probability that any relationships among variables in a study are discovered (WHO, 2006). Furthermore, the measurer error is the most troublesome source of anthropometric error. This type of error can even be accentuated by the use of multiple measurers (Simmons & Istook, 2003) – condition that was present in at least 12 out of the 79 studies reviewed (Table 2.3), where the inter-measurer reliability and precision should have been calculated to avoid errors. This situation could also become important for the other 67 studies that did not mention (NM) or not specify (NS) the number of measurers involved in the measurement process. Regarding the number of measurers, some studies were considered to be NS, (see Table 2.3) since they mentioned the use of more than one person to collect the measures but did not specify how many of the evaluators actually took the measurements. An example of this is the study by Sadeghi et al. (2014) where the measurements were carried out by a team of 30 engineers and one anthropologist. Still, it was not specified if the engineers or the anthropologist took the measurements or who was a recorder and who was the measurer or if they were able to switch roles.

Only three out of the 79 studies included measurements by only one measurer (Cengiz, 2014; Ismaila et al., 2013; Zetterberg & Ofverholm, 1999).

Regarding precision, only two of the studies reviewed mentioned it (Spasojević et al., 2015; Widyanti et al., 2015), just one study evaluated precision without mentioning the term (Guan et al., 2012), and two studies mentioned and evaluated precision and presented the results (Lee et al., 2013; Marklin et al., 2010) (Table 2.1). The three studies that evaluated precision used it as an indicator or had the following procedure:

- Minimum and maximum absolute difference between any two measurers, the mean and SD of absolute differences among all measurers (Marklin et al., 2010), the mean of the absolute differences ranged from 2 mm to 18 mm, except for weight (Guan et al., 2012). Marklin et al. (2010), was the only one of the 79 papers that actually mentioned and evaluated both precision and reliability, using two tests to assess the latter, providing also the results of the calculations used for each indicator. Further analysis will be made in sections below. The mean absolute difference (MAD) can be used for assessing observer precision since it has a low correlation with dimensional magnitude and its own magnitude can be readily used as a standard against which measurer performance can be tested (Gordon & Bradtmiller, 1992). A limitation of the MAD is that, although it describes observer error magnitude, it does not indicate the proportion of observation variance that is free from any error. This is relevant in anthropometric surveys, since a dimension with a relatively high within-subject variability compared to between-subject variability has no utility for describing and categorizing anthropometric dimensions (Gordon & Bradtmiller, 1992).

- Use of two measurements per dimension, but additional measurements were made until the difference between two measurements was 2mm, then, the average of each pair of measurements was used (Lee et al., 2013). This level is rigorous, specially for bigger measurements like the ones measured in this study aiming for helicopter cockpit design, such as sitting eye height. This level might work since it is very strict, but it is often used for smaller dimensions, such as fingers (Ulijaszek & Kerr, 1999).

It is relevant to point out that only three out of the 79 papers evaluated precision, despite the fact that precision is the most basic indicator of an anthropometrist's expertise. The TEM is also a commonly used measure of precision (Arroyo et al., 2010; Frisancho, 2008) and is advised to be used together with the MAD by Gordon and Bradtmiller (1992) and is also presented as such in the ISO 7250-2 (ISO, 2010b) as follows: *"The number of measurers and information on the skill of each measurer, such as intra-observer mean absolute difference or technical error of measurement or repeated measurements, are shown when such data are available. When more than one measurer is involved, the methods used to control the quality of the measurement technique are documented..."*

It is important to highlight that 14 of the 79 studies mentioned reliability (Dawal et al., 2012; Ismaila et al., 2013; Khadem & Islam, 2014; Laing et al., 1999; Lavender et al., 2002; Mokdad, 2002; Pourtaghi et al., 2014; Sadeghi et al., 2014; Sadeghi et al., 2015; Widyanti et al., 2015; Xiong et al., 2008; Yang et al., 2007; Zetterberg &

Ofverholm, 1999) or synonymous terms, such as, repeatability (Marklin et al., 2010). However, only six of the 79 studies evaluated repeated measurements using reliability where only Dawal et al. (2012); Laing et al. (1999); Marklin et al. (2010); Pourtaghi et al. (2014) and Xiong et al. (2008) provided results for their reliability indicators. In these studies, several indicators were used, such as t-test (Du et al., 2008); reliability coefficient (Pourtaghi et al., 2014); Pearson correlation coefficient (Dawal et al., 2012); repeatability coefficient (Marklin et al., 2010), intraclass correlation coefficient (Marklin et al., 2010; Xiong et al., 2008) and coefficient of variance (Laing et al., 1999).

At a first glance, it seems that there are a small number of studies in this review that considered the evaluation of reliability. Nonetheless, it is important to mention that only two out of the six databases presented in the ISO 7250-2 (ISO, 2010b), that used manual measurements, considered the evaluation of reliability. In the following paragraphs, studies that evaluated reliability will be discussed by the indicators they used.

In the studies reviewed, only one used paired samples t-tests to assess the inter- and intra-measurer reliability (Du et al., 2008). The use of this test is consistent with the procedure used by Steenbekkers (1993) and reinforced by Goto and Mascie-Taylor (2007), who indicated that inconsistency between two measurements can be assessed using a paired samples t-test, which determines whether the mean is significantly different or not. However, Bruton et al. (2000), indicated that paired samples t-test, are better suited for obtaining systematic bias among observations and are commonly used in reliability testing, but they have the limitation of only providing results about systematic differences between the means of two groups of observations, not taking into account individual differences.

A better alternative is using the reliability coefficient (R), as used by Pourtaghi et al. (2014). The R, is useful since it can be readily calculated using random effects analysis of variance where measurer effects are nested within subject effects, thus providing results related to the error free proportion of variance (Gordon & Bradtmiller, 1992). In other words, this coefficient shows the proportion of between-subject variance free from measurement error (Arroyo et al., 2010). Additionally, because R is unit-free, it allows to perform observer variations among diverse magnitude variables (Gordon & Bradtmiller, 1992).

The repeatability coefficient can also be used to calculate observer error over measurements. In this review only Marklin et al. (2010) used it. Care should be taken when using this coefficient, since it may confuse readers, mainly because coefficients, like the R, are unit-free and in a range from zero to one, while the repeatability coefficient has the units of the measurement, for example millimeters. In general the reliability coefficient is not a very commonly used indicator (Bruton et al., 2000) and literature related to anthropometrics shows that there are two ways to calculate it, varying slightly between the two ways to do it (Bland and Altman, 1986; Bland, 1987).

Pearson correlation coefficient (r) was another method used in one of the studies reviewed (Dawal et al., 2012). The r reflects the extent of association between two groups of measurements, or the consistency of the position within them. However, this coefficient fails to detect systematic errors, thus reliability calculations using r can present highly correlated variables that at the same time are poorly repeatable (Bruton et al., 2000).

The intra-class correlation coefficient (ICC) can be used to bridge over the restrictions of r and it was used in two of the papers reviewed, to test the inter- and intra-measurer reliability (Marklin et al., 2010; Xiong et al., 2008). The ICC is an indicator computed using variance estimates obtained through the separation of total variance into between-and within-subject variance (ANOVA). It has the strength of showing the extent of consistency and agreement between measurements (Bruton et al., 2000).

The coefficient of variation (CV) is an indicator for measurement error commonly used (especially where multiple repeated tests are standard procedure), which shows the standard deviation as a proportion of the mean in percentage, thus being independent of units (Bruton et al., 2000). This method was used by only one author (Laing et al., 1999). This indicator has a limitation, as Bland (1987) clearly explains it, the weakness of presenting observer error as a percentage, is that the percentage of the smaller measurement result will differ highly from the percentage of the largest measurement. It is more suitable to use ICC instead of the CV since the ICC establishes the relationship of error size variation to the size of the variation studied (Chinn, 1991). Despite its limitations, Bruton et al. (2000) mentioned that the CV is a pertinent indicator to assess reliability.

During the last three decades a great effort has been done by means of the ISO standards to have more accurate and reliable anthropometric measurements. Still, the results in the area of anthropometric surveys for ergonomics purposes does not differ from the idea presented more than three decades ago by Ulijaszek and Mascie-Taylor (1994). These authors explained that reports of growth and physique measurements in human populations rarely include estimates of measurement error and this issue could be due to a lack of standardized terminology to describe the reliability of measurement in a clear and understandable way.

Finally, the results from the present review shows that despite the fact that anthropometric measurements need to present direct indicators of observer errors (WHO, 2006), only 24 of the 79 papers mentioned at least one of the terms and only nine evaluated at least one of them. Only one study (Marklin et al., 2010) both mentioned and evaluated reliability and precision. None of the reviewed studies mentioned and evaluated all the three terms accuracy, precision and reliability.

2.3.3. Other findings that may affect the accuracy, precision and reliability

The results show that only a few studies have evaluated the level of accuracy, precision and reliability. Furthermore, a deeper analysis of the reviewed papers can be done through the examination of three factors that may affect the measurement error, as described in the following sections: training, measurement tools and procedures.

2.3.3.1. Training

Of the reviewed studies, only 16 studies considered training procedure before the data collection (Table 2.3). This is a very important aspect since consistent training can reduce differences between measurements taken by different people (Bragança et al., 2016). In most studies, training included a theoretical approach about anthropometry, as well as practical training. One of the studies has also considered training by showing a video of the anthropometric measurements and by test-measuring the required dimensions (Du et al., 2008).

The majority of studies did not specify the timeframes used in training (Table 2.3). Nevertheless, with the available information it can be stated that there are significant discrepancies related to the training time used. For example, Sadeghi et al. (2015) used a two day training session, Khadem & Islam (2014) used a three day training session, whilst other authors used a one- week training session (Karmegam et al., 2011; Mokdad, 2002).

2.3.3.2. Measurement tools

In the reviewed literature, a large amount of measurement tools were used to collect the data, where 38 of them used more than one measurement tool (Table 2.2). The most frequently used measurement tool was the anthropometer (41 out of the 79). The most used anthropometer, in 16 out of the 79 reviewed studies, was Martin Type/Siber-Hegner GPM® (Figure 2.2). The second most used tool was the caliper, where 27 studies used a sliding caliper. On the other hand, 21 studies did not mention the type of measurement tool used during their anthropometric survey (Table 2.2).

Table 2.2. Summary of the Measurements tools of the studies included in this review

Measurements tools	Type or label	Author
Anthropometer	Harpenden, Holtain	Cengiz, 2014; Flyte & Perchard., 1999; Karmegan et al., 2011; Mokdad, 2002; Oñate et al., 2012
	Lafayette	Hoque et al., 2014
	Martin Type / Siber-Hegner GPM	Cais & Chen, 2016; Chuang et al., 1997; Dawal et al., 2012; Dewangan et al., 2010; Du et al., 2008; Eksioglu, 2016; Hsiao et al., 2005; Laing et al., 1999; Lavender et al., 2002; Lee et al., 2013; Marklin et al., 2010; Pennathur & Dowling 2003; Shrestha et al., 2009; Singh et al., 2015; Wibowo et al., 2013; Widyanti et al., 2015
	Kanoon Tarrahan Ferasat Company	Sadeghi et al., 2014
	N/S	Chavalitsakulchai & Shahnavaz, 1993; Deros et al., 2009; Guan et al.,2012; Hsiao et al., 2014; Imrhan et al., 2009; Khadem & Islam 2014; Lucero et al., 2012; Mahmoudi & Bazrafshan, 2013; Matias et al., 1998; Sadeghi et al., 2015; Spasojević et al., 2015; Sutjana et al., 2008; Syuaib, 2015a; Syuaib, 2015b; Taha et al., 2009; Thariq et al., 2010; Toro & Henrich, 1997; Tunay & Melemez, 2008
Caliper	Sliding caliper	Ademola et al., 2014; Akhter et al., 2009; Bylund & Burstrom, 2006; Cais & Chen, 2016; Castilho et al., 2012; Dawal et al., 2012; Du et al., 2008; Eksioglu, 2016; Flyte & Perchard., 1999; Guan et al.,2012; Hanson et al., 2009; Hsiao et al., 2014; Khadem & Islam 2014; Laing et al., 1999; Lucero et al., 2012; Mokdad, 2002; Nag et al., 2003; Shah et al., 2015; Shrestha et al., 2009; Singh et al., 2015; Spasojević et al., 2015; Sutjana et al., 2008; Taha et al., 2009; Van Driel et al., 2013; Verhaert et al., 2011; Widyanti et al., 2015; Yang et al., 2007.
	Vernier Calliper	Ismaila et al., 2013; Wibowo et al., 2013
	Electronic digital caliper	Imrhan et al., 2009
	Skinfold calliper	Mokdad, 2002; Stålhammar & Louhevaara, 1992

Measuring Tape*	Plastic	Hanson et al., 2009; Laing et al., 1999; Lucero et al., 2012; Stålhammar & Louhevaara, 1992; Widyanti et al., 2015; Yang et al., 2007.
	Steel or metal	Ademola et al., 2014; Akhter et al., 2009; Cengiz, 2014; Dawal et al., 2012; Guan et al.,2012; Hsiao et al., 2005; Ismaila et al., 2013; Sadeghi et al., 2015
	Rigid measuring tape	Hanson et al., 2009
	Retractable tape measure	Bello & Sepenu, 2013
	N/S	Tunay & Melemez, 2008; Akhter et al., 2009; Cai & Chen, 2016; Eksioglu, 2016; Flyte & Perchard., 1999; Matias et al., 1998; Nag et al., 2003; Sadeghi et al., 2015; Syuaib, 2015a; Syuaib, 2015b; Taha et al., 2009; Toro & Henrich, 1997; Tunay & Melemez, 2008; Van Driel et al., 2013; Verhaert et al., 2011; Xiong et al., 2008
Stadiometer	N/S	Ademola et al., 2014; Chuang et al., 1997; Ismaila et al., 2013; Pourtaghi et al., 2014; Reis et al., 2012;
Others	Radial reach scale	Pennathur & Dowling 2003
	Height scale	Cais & Chen, 2016
	Ruler	Mazloumi & Mohammadreze, 2012; Mousavifard & Alvandian, 2011; Wibowo et al., 2013
	Wooden measure board	Lee et al., 2013; Sadeghi et al., 2015
	Adjustable height chair/stool	Ademola et al., 2014; Castilho et al., 2012; Cengiz, 2014; Chavalitsakulchai & Shahnavaz, 1993; Guan et al.,2012; Khadem & Islam 2014; Mahmoudi & Bazrafshan, 2013; Mokdad, 2002; Sadeghi et al., 2015; Spasojević et al., 2015; Thariq et al., 2010
	Goniometer	Mazloumi & Mohammadreze, 2012; Pennathur & Dowling 2003; Sadeghi et al., 2015.
	Graduated cone	Lucero et al., 2012
	Anthropometric Chair	Deros et al., 2009
	Mari Pistolet	Mousavifard & Alvandian, 2011
	Foot measurer	Widyanti et al., 2015; Xiong et al., 2008
N/M		Chi et al., 2012; Deros et al., 2011; Dhara et al., 2016; Genaidy et al., 1995; Gil et al., 1998;

	Gunther et al., 2008; Imrhan & Sundararajan,1992; Kawahara et al., 1998; Kumar & Garand, 1992; Mahoney et al., 2015; Nicolay & Walter, 2005; Osquei-Zadeh et al., 2012; Pourtaghi et al., 2014; Simeonov et al., 2012; Sudhakaran & Mirka, 2005; Ugurlu & Ozdogan, 2011; Wang & Chao, 2010; Werner et al., 1998; Yun et al., 2002; Zetterberg & Ofverholm, 1999; Zujnic et al., 2015

N/S: note specified. N/M:not mentioned

Following the discussion presented in section 2.3.1, it is important to mention that there is contradictory bibliography regarding instrument accuracy. One position is that the risk of inaccuracy is greater when using complex instruments versus using more simple ones. Thus, inaccuracy of measurements while using a simple measuring tape is more likely to be smaller than when using sliding scales, such as anthropometers and stadiometers (Ulijaszek & Kerr, 1999). On the other hand, Roebuck et al. (1975) mention that the accuracy is generally best approximated by the use of precisely calibrated and rigid instruments carefully positioned by trained investigators under controlled environmental conditions.

Considering the previous information, one should determine if it is better to measure with a measuring tape rather than with an anthropometer. The answer to this question firstly; depends on the specific measure to be collected. Secondly, it is important to mention that validity is the degree to which an observation measures a characteristic, and is highly related with the term accuracy since 'true' values are very difficult to be calculated (Ulijaszek & Kerr, 1999). One could also enquire about the validity of using a measuring tape to collect linear distances (e.g. popliteal height or elbow height sitting). Based on the ISO 7250-1, measuring tapes are only recommended for body circumferences measurements and not for linear distance. Nonetheless, as it is not a rigid instrument, this recommendation could be accepted or not, based on the characteristics of the measuring tape and on the characteristics of the body measurement to be collected. For example, when measuring popliteal height it would be more difficult to position one end of the measuring tape in the tendon of the relaxed biceps femoris muscle and the other end on the floor, since this equipment does not have blades or branches like the anthropometer (Figure 2.2) and it may not be very stable, thus compromising the results.

The positioning of the landmarks might also be an issue, as happens when using a 3D scanner or a skinfolds measuring device. Landmarking is a very useful tool in order to achieve better levels of accuracy, precision and reliability. Landmarking has been applied successfully in large and internationally known anthropometric surveys such as ANSUR, MC-ANSUR, ANSUR II (Gordon et al., 1988; 2012; 2013), where all the subjects were arm forces personnel. The samples of these studies may favor the landmarking process and following measurement protocols, mainly because of the highly hierarchical organizational structure and rigor present in arm forces, it could be assumed that these subjects are more willing to cooperate and strip down to light clothes than civilian subjects in other studies. Landmarking has, however, its limitations mainly because when applied in non-arm forces work settings, landmarking can present issues related to privacy and cultural/religious beliefs that may downsize subject's participation. Thus, just a few exposed areas are usually marked and the rest of the landmarks are located by palpation over clothes and then the measurement is performed. This procedure was followed by a very relevant anthropometric survey by Guan et al. (2015), where the sample was composed of only U.S truck drivers and the measurements were performed with and without subject's shoes in some cases.

Figure 2.2. Martin type anthropometer

Considering the previous information, there are four studies that present instruments that may be inadequate to collected the required measurements (Bello & Sepenu, 2013; Hanson et al., 2009; Sadeghi et al., 2015; Stålhammar & Louhevaara, 1992). For example, all of these studies used a measuring tape to measure linear distances, breadths and depths, instead of using an anthropometer and/or sliding /spreading calipers. Finally, other authors (Hanson et al., 2009; Laing et al., 1999; Lucero et al., 2012; Stålhammar & Louhevaara, 1992; Widyanti et al., 2015; Yang et al., 2007) used plastic measuring tape (tailor's measuring tape type), which may be considered as an unreliable instrument since it is made from a material that can stretch and get deformed over time (Bragança et al., 2016).

2.3.3.3. Procedures for data collection

Having a standardized procedure for data collection will certainly minimize the measurement error and is more likely to allow comparisons with other anthropometric measurements from different populations. ISO 7250-1 (ISO, 2008) provides some information with the purpose of standardizing the data collection procedures: (i) description of anthropometric measurements, (ii) clothing of subject, (iii) body symmetry, (iv) posture, (v) instruments, and (vi) support surfaces (floor or sitting surfaces).

It is relevant to discuss that none of the reviewed papers were published before the first version of the ISO 7250, 1988. Despite that, only ten of the reviewed studies mentioned that the measurements were performed following the recommendations on the standard (Table 2.3). These results should be considered with caution since:

a) 23 studies used the measurements defined by other relevant authors, such as: Pheasant (2003); Kroemer and Granjean (1997); Gordon et al. (1988) , Evans et al. (1988) and Hertzberg (1968). It is important to highlight that the dimensions from the previous authors present high similarities with the dimension defined by the ISO 7250.

b) Other eight authors (Cais & Chen, 2016; Mazloumi & Mohammadreze, 2012; Mousavifard & Alvandian, 2011; Sadeghi et al., 2014; Wang & Chao, 2010; Werner et al., 1998; Yang et al., 2007; Yun et al., 2002) only gathered measurements that are not defined in the ISO 7250-1. It needs to be said that in itself this is not a problem, since the ISO standard mentions that the basic list can be supplemented by specific additional measurements.

c) 14 authors used both dimensions present in ISO 7250-1 and additional dimensions (Du et al., 2008; Flyte & Perchard., 1999; Kawahara et al., 1998; Nag et al., 2003; Lee et al., 2013; Oñate et al., 2012; Sadeghi et al., 2015; Taha et al., 2009; Thariq et al., 2010; Toro & Henrich, 1997; Tunay & Melemez, 2008; Ugurlu & Ozdogan, 2011; Verhaert et al., 2011; Xiong et al., 2008). Furthermore, the ISO 15535 mentions that measurements that are different from those specified in ISO 7250-1 can also be collected according to the purpose of the investigation. In such cases, definitions, methods, instruments and measurement units shall be clearly indicated in the report. This was the case for Oñate et al. (2012) that used the ISO 8559 standard for clothing design, where most measurements are related to girths and body curvatures. The authors of this review believe that when measurements have not been extracted from ISO 7250-1, it is important to clearly defining them, thus indicating the relevant related anatomic points, and if possible bones, since these are more easily located and represent a solid point to place the measurement instruments. However, if measurements required do not consider bony body parts, it should clearly specify the location of instrument placement in order to minimize the measurement error. One example of this is thigh clearance, where one of the blades of the anthropometer should be placed on the highest point (on the top) of the thigh. Although thigh clearance is part of ISO 7250-1, it shows that when measurements consider soft parts, and clearance is being sought, the tallest, biggest or widest parts should be used as reference points. This approach was done in ANSUR II (Gordon et al., 2012) with similar measurements that use “soft” landmarks, such as chest circumference or shoulder circumference, in order to actually measure the whole spectrum of the measurement, especially in bigger subjects. The consideration of a standard posture of the subjects and the use of proper instruments selection is also a key aspect, where the researcher can follow ISO 7250-1 standard as a guideline and complement it with other relevant technical text in order to accommodate their required measurements for particular needs.

Table 2.3. Characteristics of training and measurements procedure of each study included.

Author and year	Training	Number of measurers	Mention ISO 7250	Measurements considered		Measurement Defined		Measurement procedure		
				ISO 7250	Not ISO 7250	Text	Figure	Light clothes	No shoes	Posture *
Ademola et al., 2014	N/M	N/M	✓	✓	X	N/S	X	N/M	✓	✓
Akhter et al., 2009	N/M	N/M	X	✓	X	✓	X	N/M	N/M	✓
Bello & Sepenu, 2013	N/M	N/M	X	✓	X	✓	X	✓	N/M	✓
Bylund & Burstrom, 2006	N/M	N/M	X	✓	X	✓	X	N/M	N/A	✓
Cais & Chen, 2016	N/M	N/M	X	X	✓	✓	✓	N/M	N/A	✓
Castilho et al., 2012	N/M	N/M	X	✓	X	✓	X	N/M	N/M	N/M
Cengiz, 2014	✓	1	✓	✓	X	✓	X	✓	✓	✓
Chavalitsakulchai & Shahnavaz, 1993	N/M	N/M	X	✓	X	X	✓	✓	✓	✓
Chi et al., 2012	N/M	N/M	X	✓	X	✓	X	✓	N/A	✓
Chuang et al., 1997	N/M	N/M	X	✓	X	✓	X	✓	✓	✓
Dawal et al., 2012	✓	N/S, at least 2	X	✓	X	X	✓	✓	✓	✓
Deros et al., 2011	N/M	N/M	X	✓	X	X	✓	N/M	N/M	N/M
Deros et al., 2009	N/M	N/M	✓	✓	X	X	✓	✓	✓	✓
Dewangan et al., 2010	N/M	N/M	✓	✓	X	X	X	✓	✓	✓
Dhara et al., 2016	N/M	N/M	X	✓	X	X	X	N/M	N/M	N/M
Du et al., 2008	✓	N/M	X	✓	✓	✓	X	N/M	N/M	N/M

Eksioglu, 2016	N/M	N/M	✓	✓	X	✓	X	✓	✓	✓
Flyte & Perchard., 1999	N/M	N/M	X	✓	✓	✓	X	N/M	N/M	N/M
Genaidy et al., 1995	N/M	N/M	X	✓	X	X	X	N/M	N/M	N/M
Gil et al., 1998	N/M	N/M	X	✓	X	X	X	N/M	N/M	N/M
Guan et al.,2012	✓	N/S, at least 2	✓	✓	X	X	X	W/cloth.	X	✓
Gunther et al., 2008	✓	N/S, at least 2	X	✓	X	✓	X	N/M	N/A	✓
Hanson et al., 2009	✓	N/M	✓	✓	X	X	X	N/M	N/M	N/M
Hoque et al., 2014	N/M	N/M	X	✓	X	X	✓	✓	✓	✓
Hsiao et al., 2005	N/M	N/M	X	✓	X	X	✓	✓	✓	✓
Hsiao et al., 2014	N/M	N/M	X	✓	X	✓	X	W/cloth.	X	✓
Imrhan & Sundararajan,1992	N/M	N/M	X	✓	X	✓	X	N/M	N/M	N/M
Imrhan et al., 2009	N/M	N/M	X	✓	X	✓	✓	N/A	N/A	✓
Ismaila et al., 2013	✓	1	X	✓	X	✓	X	✓	✓	✓
Karmegan et al., 2011	✓	N/S, at least 2	X	✓	X	✓	✓	✓	✓	N/S
Kawahara et al., 1998	N/M	N/M	X	✓	✓	X	✓	N/M	N/M	N/M
Khadem & Islam 2014	✓	2	X	✓	X	N/S	X	W/cloth.	✓	N/S
Kumar & Garand, 1992	N/M	N/M	X	✓	X	N/S	X	N/M	N/M	N/M
Laing et al., 1999	✓	2	X	✓	X	N/S	X	✓	N/M	N/M
Lavender et al., 2002	N/M	N/M	X	✓	X	✓	X	X	X	✓
Lee et al., 2013	N/M	N/M	X	✓	✓	X	✓	N/M	N/M	✓

Lucero et al., 2012	N/M	N/M	X	✓	X	N/S	X	W/cloth.	X	N/M
Mahmoudi & Bazrafshan, 2013	N/M	N/M	X	✓	X	X	✓	✓	✓	✓
Mahoney et al., 2015	N/M	N/M	X	✓	X	X	✓	N/M	N/M	✓
Marklin et al., 2010	N/M	2	X	✓	X	✓	✓	W/cloth.	X	✓
Matias et al., 1998	N/M	N/M	X	✓	X	N/S	X	N/M	N/M	N/M
Mazloumi & Mohammadreze, 2012	N/M	N/M	X	X	✓	X	✓	N/M	N/M	N/M
Mokdad, 2002	✓	N/S, at least 2	X	✓	X	X	✓	N/M	N/M	✓
Mousavifard & Alvandian, 2011	N/M	N/M	X	X	✓	✓	X	N/M	N/M	N/M
Nag et al., 2003	N/M	N/M	X	✓	✓	X	✓	N/M	N/A	✓
Nicolay & Walter, 2005	N/M	N/M	X	✓	X	✓	X	N/M	N/A	N/M
Oñate et al., 2012	N/M	N/M	X	✓	✓+	N/S	X	✓	✓	✓
Osquei-Zadeh et al., 2012	N/M	N/M	X	✓	X	✓	X	✓	✓	✓
Pennathur & Dowling 2003	N/M	N/M	X	✓	X	X	✓	N/M	N/M	✓
Pourtaghi et al., 2014	✓	N/M	✓	✓	X	X	✓	✓	✓	✓
Reis et al., 2012	N/M	N/M	X	✓	X	✓	X	N/M	N/M	✓
Sadeghi et al., 2014	✓	N/S, at least 2	X	✓	X	N/S	X	N/M	N/M	✓
Sadeghi et al., 2015	✓	N/S, at least 2	✓	✓	X	X	✓	✓	✓	✓
Shah et al., 2015	N/M	N/M	X	X	✓	✓	X	N/A	N/A	N/M
Shrestha et al., 2009	N/M	N/M	X	✓	✓	N/S	X	✓	✓	✓

Simeonov et al., 2012	N/M	N/M	X	✓	X	N/S	X	W/cloth.	X	N/M
Singh et al., 2015	N/M	N/M	X	✓	X	N/S	X	N/S	N/S	N/S
Spasojević et al., 2015	✓	N/S , at least 2	X	✓	X	N/S	X	W/cloth.	X	✓
Stålhammar & Louhevaara, 1992	N/M	N/M	X	✓	X	✓	X	✓	✓	✓
Sudhakaran & Mirka, 2005	N/M	N/M	X	✓	X	N/S	X	N/M	N/M	N/M
Sutjana et al., 2008	N/M	N/M	X	✓	X	X	✓	W/cloth.	✓	✓
Syuaib, 2015a	N/M	N/M	X	✓	X	N/S	X	N/M	N/M	N/M
Syuaib, 2015b	N/M	N/M	X	✓	X	X	✓	N/M	N/M	N/M
Taha et al., 2009	N/M	N/M	✓	✓	X	✓	X	✓	✓	✓
Thariq et al., 2010	N/M	N/M	X	✓	X	X	✓	W/cloth.	✓	✓
Toro & Henrich, 1997	N/M	N/M	X	✓	X	✓	✓	N/M	N/M	N/M
Tunay & Melemez, 2008	N/M	N/M	X	✓	X	✓	X	W/cloth.	N/M	N/M
Ugurlu & Ozdogan, 2011	N/M	N/M	X	✓	X	X	X	N/M	N/M	N/M
Van Driel et al., 2013	N/M	N/M	X	✓	✓	✓	X	N/M	N/M	N/M
Verhaert et al., 2011	N/M	N/M	X	✓	✓	N/S	X	N/M	N/M	N/M
Wang & Chao, 2010	N/M	N/M	X	✓	✓	X	✓	N/M	N/M	N/M
Werner et al., 1998	N/M	N/M	X	✓	✓	N/S	X	N/M	N/M	N/M
Wibowo et al., 2013	N/M	N/M	X	✓	✓	N/S	X	N/S	N/S	N/S
Widyanti et al., 2015	✓	N/M	X	✓	X	X	✓	✓	✓	✓
Xiong et al., 2008	N/M	2	X	✓	✓	N/S	X	N/S	N/S	✓
Yang et al., 2007	N/M	N/M	X	X	✓	✓	✓	N/A	N/A	N/S

Yun et al., 2002	N/M	N/M	X	X	✓	N/S	X	N/A	N/A	N/M
Zetterberg & Ofverholm, 1999	N/M	1	X	✓	X	N/S	X	N/M	N/M	N/M
Zujnic et al., 2015	N/M	N/M	X	✓	X	N/S	X	W/cloth.	X	N/S

N/S: not specified, author quoted instead of providing a clear procedure or if dimensions mentioned in results table but were not explained in detail; N/S, at least 2: number of measurers not specified, only reference to at least 2 teams; N/M: not mentioned; N/A: not applicable, i.e. hand, face or other measurements that are not affected by clothes or shoes. W/cloth.: with working clothes o regular clothes

* It is related to the standard posture of sitting: knees and hips flexed at 90° (right angle), supporting the feet flat on the floor and head oriented in the Frankfurt plane. Also, was considered for the standard standing/sitting posture

+ Author quoted ISO 8559

Considering the previous points, this critical situation needs to be addressed since only six studies defined the measurements using text and figure, 45 studies used only text or figure and seven studies did not present any definition for their measurements (see Table 2.3). It is important to point out that 21 studies presented the dimensions in an unspecified manner, thus they were classified as not specified (N/S) since the authors only presented the dimensions in the results tables, not specifying referential landmarks nor any other particular definition (Table 2.3).

Regarding the clothing of the subjects, there are four studies that need to be excluded of the analysis since they considered measurements that are not affected by clothes such as: hand dimensions and head/neck/face dimensions (Imrhan et al., 2009; Shah et al., 2015; Yang et al., 2007; Yun et al., 2002). For the remaining 75 studies, in 23 studies the subjects were measured in t-shirts and shorts or lightly clothed. Is of interest the paper by Oñate et al., (2012) that made reference to another ISO standard (ISO, 1989), where it is stated that the procedure of measurement should be done nude or lightly clothed. On the other hand, 12 studies performed the measurements with the participants wearing casual or working clothes (See table 2.3). A particular study was the one by Hsiao et al. (2014) since they performed the measurements with the subjects both wearing light clothes and working clothes. This paper actually shows a very interesting approach that should be given more consideration, and shows a clever way to overpass the gap between standard measuring procedures (light clothing) and future practical design/intervention implications. Since the sample used by Hsiao et al. (2014) were firefighters that inherently use several protective equipment such as helmets, masks, boots and bulky jackets; the procedure used in this publication allows calculating easily and realistically the variation of the anthropometric dimensions experienced by subjects while wearing real work protective garments. Since human work in its essence is heterogeneous, the authors of this review believe that this approach in field anthropometric surveys should be more used in order to properly address variation in anthropometric dimensions among workers, especially for those who need to use protective equipment, use complex tools or work in adverse climate conditions, such as in cold environments. This is reinforced by Guan et al. (2015) who performed some measurements (height) with and without shoes when subjects were wearing the shoes that used while driving, they even made a thorough description on the shoe types worn by male and female truck drivers.

Other three studies were labelled as N/S since the authors provided references to other authors instead of stating a clear procedure regarding clothing (Singh et al., 2015; Wibowo et al., 2013; Xiong et al., 2008). This was done since referring to an author in particular does not necessarily communicate the actual procedure followed. For example, in the case of Wibowo et al., 2013, they quoted Pheasant & Halsegrave 2006 regarding subject clothing. They measured Indonesian farmers, where in this country the main religious tendencies might difficult to perform measurements on "unclothed" women, as suggested by Pheasant & Halsegrave 2006. The authors of this review think that without going into further detail, one can both cite the author and describe briefly the clothes the subject used and other procedure related circumstances. Finally, 37 studies did not mention the clothing of subjects. It is relevant to discuss that in some countries religion or culture imply that certain measurements must be taken with clothes, especially when women are the ones being measured, as it was stated by Karmegam et al. (2011). According to the authors' experience, it is common that field anthropometric surveys are taken also with clothes (at least shirt /dress/pants and no shoes). This happens because it is hard to convince people to undress at their jobs or to change into light clothes and then put again their regular clothes, especially if there are no suitable facilities and for the time loss that may compromise productivity. This was clearly stated by Guan et al. (2015) as the main reason why they measured their subjects with their regular clothes. This can usually be solved with subject`s compensation, however in developing countries, the authors of this review recognize the challenges that can be found, since funding can be an issue, thus the incentive for subjects to undress or participate might not be enough.

The posture adopted by the participants is marked as being a factor that affects errors in anthropometry (Kouchi & Mochimaru, 2011). To minimize the effect of this, many of the studies reviewed (42 out of the 79) measured the participants sitting and/or on the standard standing position. However, 31 studies did not mention the adopted posture at all, and six studies did not specified the posture used or quoted another in their procedure, thus they were labeled as not specified N/S since no explicit description of the posture was made (Karmegan et al., 2011;

Khadem & Islam 2014; Singh et al., 2015; Wibowo et al., 2013; Yang et al., 2007; Zujnic et al., 2015).

Furthermore, some authors evaluated measurements with participants wearing shoes, such eye height standing, shoulder height standing, elbow height standing (Lavender et al,. 2012; Lucero et al., 2012; Simeonov et al., 2012), upper leg height (Spasojević et al., 2015) and knee height sitting (Zujnic et al., 2015). Another author (Guan et al., 2012) was not explicit about if some measurements, such as popliteal height, were measured with or without shoes, since they sometimes measured height both with and without shoes, depending if the subjects wore their typical driving shoes. However, they based their measurements on the definitions present in ANSUR (Gordon et al., 1989), which states that popliteal height should be measured barefoot. In this particular case, one of their aims was to describe the types of shoes worn typically by male and female truck drivers, which we believe is very useful for design/ergonomics purposes (i.e. actually knowing which type of shoes are worn by truck drivers). This paper derives from the extensive technical report of U.S truck drivers' anthropometrics (Guan et al., 2015). The procedure followed by these authors is consistent with the view of the authors of the current review, and it is a good example on how to practically overpass the high variability in shoe types, being similar to the approach previously made regarding clothing. Care should be taken if not following and describing the exact measurement definition nor procedure, since it may lead the reader to believe that some type of error might be present because measurements have been made with shoes. This is the reason why it is recommended to always measure the participants barefoot, keeping in mind that shoes may naturally vary according to culture, fashion, and country. To get more representative values of the sample under study, an option is to measure the shoe heel and, in the cases where this is not possible for the researchers, an alternative would be to consider shoe correction as a value between 2–3 cm (Castellucci et al., 2014). Another author, Marklin et al. (2010), who measured relevant dimensions such as popliteal height with shoes, did apply corrections for both clothing and shoes in order to make comparisons with other databases that measured subjects with light clothes as the standard procedure that should be used when doing those comparisons. Also when measuring people with their clothes, the results may be influenced by the geographical location where colder or hotter weather has an impact on the type of clothes used by the subjects and that may not be the clothes actually used at their work. Thus as stated previously, while discussing the paper of Hsiao et al. (2014), a practical suggestion could be to present actual data of workers with and without clothes, ideally measuring both conditions.

Finally, based on the findings of this study it can be concluded that more importance should be given to the procedure of anthropometric surveys in peer reviewed journals, not only on how to collect the data (measurement tools, training and data collection procedures) and test the measurement error, but also on how the data is presented in a scientific paper, since many authors did not mention nor specified relevant information of the data collection process. Generally technical reports use very comprehensive and clear procedures, as those used by Gordon et al. (1988; 2012), where they even had observer error tested daily (Gordon et al., 2013). These reports should be used as a guideline in order to point out the most relevant parts that should be included in a peer reviewed paper addressing manual anthropometric procedures, such as: detailed descriptions of measuring tools; anthropometric measurement definitions specifying relevant landmarks, subjects posture and clothing/shoes; number of observers with the corresponding observer error testing results; and presenting error levels specifically for each dimension. Technical reports offer a great guideline which should be transferred, in a more summarized format, to any peer reviewed paper that takes anthropometric measurements manually, where a small table showing the above recommendations can be conveniently included in the paper.

Specific dimension observer error limits are present in highly rigorous technical reports (Gordon et al., 1988; 2012; 2013; Guan et al., 2015), but the reader might think about the practical design implications of, for example, a 5 mm error, in a particular dimension. The answer depends on the dimension itself. According to Norton and Olds (1996), the smaller the measure, the lower the error tolerance should be. This means that, for example, when designing highly specific garments or equipment for smaller body parts (face, hands and feet) a 5mm error difference could have a critical impact on the product´s fit. For example, a CPAP mask, aircraft masks, gloves, protective masks or shoes that are poorly fitted, can cause discomfort and/or injury, besides not achieving the desired performance level. Conversely, bigger dimensions may be more permissive, but that does not mean that observer error should be unaccounted for.

Another relevant consideration is that manual measurements are standards, which can be used to validate 3D scanned derived dimensions (ISO, 2010a). 3D scans measurements are not free from error. The main sources of error in this type of measurement are related to the devices (software and hardware) and to the measured participants, mainly because of their adopted posture and of the poor landmarking (Kouchi & Mochimaru, 2011). The validation of 3D derived measurements using traditional measurements has been followed in peer-reviewed papers (Lu & Wang, 2010; Sims et al., 2012). However, it has been acknowledged that the quality parameters of these studies are not usually consistent, mainly because of the lack of explicit accuracy standards and quality evaluation protocol procedures (Kouchi and Mochimaru, 2011). Thus, it could be implied that if measurement error of manual anthropometric methods is not tested, even the use of the most advanced technology could be improperly validated, producing the obvious negative outcomes. It is therefore relevant to evaluate, wherever possible, observer differences between anthropometrists and to explicitly show the results in peer-reviewed papers. It is also relevant to designate a criterion to both assess anthropometrists error and training novel anthropometrists, specially throughout the execution of the anthropometric surveys in order to maintain quality of measurement, and to avoid deviations during long periods of measurements (Ulijaszek & Kerr, 1999). Since in anthropometry accuracy is related to the “gold standard” which is used to compare the results of the new anthropometrists against the expert anthropometrists (Norton & Olds, 1996), the authors of this paper suggest that when significant discrepancies appear between experienced anthropometrists, both measuring techniques and measuring instruments, should be tested and compared to reduce the difference and establish an agreement among the anthropometrists on practical error levels.

2.3.4. Limitations

A limitation of this study is the fact that some relevant articles might have not been considered due to the wide variety of terminology used to refer to the same issues. Another limitation is the fact that technical reports were excluded from this analysis and only used as a reference guide, since in general those reports are not publicly available, which makes the peer-reviewed papers published in scientific journal the most common source of information about the use of anthropometrics in an ergonomics context.

This work has also some inherent limitations, which researchers using this information should be aware of when interpreting the results presented in this paper. This literature review was based on peer-reviewed journals found in only two specific bibliographic databases (Scopus and PubMed). Although it is known that these databases cover a very wide range of different areas, searching in different databases, such as Google Scholar, or considered conference articles, could also have had relevant information that might have been relevant to this review.

2.4. Conclusion

The objective of this paper was to evaluate, though a literature review, whether if the currently available anthropometric studies of working adult populations in the field of ergonomics, take in consideration precision, reliability or accuracy issues. After reviewing the 79 papers it can be concluded that this topic is poorly addressed in the literature, as only 27 studies mentioned at least one of the terms and none of the studies evaluates all of the terms.

Only 3 studies evaluated precision, where the most used indicator was the MAD, used in two of these studies. The six papers that assessed reliability, four presented the recommended methods such as the ICC, which allows the identification of individual differences and systematic errors; the R and the CV.

Regarding the variables that may affect precision, reliability and accuracy, the majority of the papers reviewed presented great differences in terms of the measurement tools used. Furthermore, there is a clear lack of information regarding the training and procedures for anthropometric data collection.

Finally, more attention should be given to the procedures used to collect anthropometric data for ergonomics purposes. They should take in consideration the procedures defined in the relevant standards and technical reports, test for measurement error and report the entire information explicitly when presenting the collected data.

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CHAPTER 3| Anthropometric characteristics of Chilean workers for ergonomic and design purposes

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Obtaining an appropriate match between a product and its end-users requires anthropometric data, which are typically outdated and show variations among different countries. Chile had its anthropometric data taken nearly 20 years ago, thus they are probably outdated. The purpose of this paper is to describe some anthropometric characteristics of Chilean workers. An anthropometric survey involving 27 measures and five calculated body dimensions was conducted in 2016. The measurements were based on ISO 7250 and ISO 15535 to ensure the highest standards possible, and a total of 2946 workers, aged from 18 to 76 years old, participated in the survey. The results showed that Chilean workers have smaller dimensions than Dutch and US workers but have larger dimensions than South Koreans. The data presented in this paper constitute the most up-to-date anthropometric dataset describing the dimensions of Chilean workers.

Practitioner summary: In Chile, women are smaller and weigh less than men, and both of these populations have high BMIs. In addition, the Chilean population exhibits substantial differences compared with other international adult populations. The data presented in this paper should be used as a reference when designing for Chilean workers.

Keywords: Anthropometry, Chile, design, ergonomics

3.1. Introduction

Physical accommodation, usually defined as the process of taking the morphology of end-users into consideration when designing new products or spaces (Garneau and Parkinson, 2016), is key to achieving one of the main objectives of ergonomics, which involves fitting tasks and workspaces to end-users (Kroemer and Grandjean, 1997; Pheasant and Haslegrave, 2006). The anthropometry of populations is a key input for achieving high levels of physical accommodation. Recent studies have reported an increasing prevalence of musculoskeletal problems in general and in working populations in both developed and developing countries (Ahacic and Kåreholt 2010; Hagen, et al. 2011; Dianat et al. 2015). In fact, if a product shows a low level of matching with a particular end-user population, the product could increase the amount of biomechanical stress placed on joints and muscles, thus contributing to a relevant extent to the occurrence of musculoskeletal disorders (Spyropoulos et al. 2007; Kushwaha and Kane 2016) and additionally have an impact on cognitive performance and preference (Castellucci et al. 2017).

Anthropometric dimensions are key to product sustainability because the occurrence of significant mismatches in user-product interactions commonly results in the users no longer buying or discarding the products, which would eventually force the manufacturers to change product lines and consume more raw materials; thus, a proper match between user dimensions and products helps produce less waste and decrease the obsolescence of a given product (Nadadur and Parkinson 2013). To achieve an effective design, it is necessary to establish the context in which the product/space will be used and identify the future end-users. If available, any existing anthropometric databases should be searched to obtain the information needed to implement design criteria. If there is no database for the end-user population, the dimensions should be designed based on the end-users or extrapolated from other populations (Das and Sengupta 1996; Molenbroek, Mantas, and DeBruin 2011). This approach has been used in several studies in a wide range of fields and applications for working populations. For example, some studies generated an anthropometric database for later use, such as a database of UK firefighters (Stirling 2005), whereas others have, in addition to collecting fire-fighter anthropometrics, tested and recommended designs for specific gear, such as protective gloves (Hsiao et al., 2015). The latter approach is usually observed in large-scale projects associated with technical reports published by government agencies. In fact, many technical reports serve as a reference regarding anthropometrics because they were obtained based on a considerably large sample size and involved very rigorous procedures for data collection and error testing. These types of studies mainly focused on military personnel (Gordon et al. 1989), marine corps (Gordon et al. 2013) and other military agencies, such as air force personnel (da Silva, Halpern, and Gordon 2017), and are often financed with a considerable budget.

Sample adherence is quite difficult, particularly when performing anthropometric surveys in a non-military context. Other studies have addressed specific workers, such as truck drivers (Guan et al. 2012), and encountered issues that were not identified in military surveys. For example, the researchers had to measure people with their clothes on and only once because they used truck stops to take the measurements, and any request to undress more than pants and t-shirts would have decreased the number of subjects that participated. Additionally, any error had to be corrected before the subjects left (Guan et al., 2012). The previously cited study, which was carried out by NIOSH, features a very comprehensive anthropometric survey of USA truck drivers that aimed to document all dimensions relevant to seating and cabin designs in trucks. Additionally, the abovementioned study also described the shoe types that the participants wore while driving as well as their ethnicity, region, and type of truck, among other variables. The study methodology used in truck cabin design is not an isolated effort because many other researchers have utilized a similar approach to address the design needs of very specific working populations, such as the design of helicopter cabins for Koreans (Lee et al. 2013), flotation suits for UK offshore workers (Stewart, Ledingham, and Williams 2017), tractor and hand tool designs for Nigerian farmers (Obi, Ugwuishiwu, and Busayo 2015; Obi 2016), milk churner designs for female Ugandan farmers (Mugisa et al. 2016), respirators for USA workers (Bradtmiller, Friess, and Zhuang 2004), tools and furniture for Norwegian light industry and office workers, and even some other not very common devices such as desk bikes (Cho, Freivalds, and Rovniak 2017). The above-mentioned examples are not practical for the Chilean population because the approach is often reactive rather than proactive (Mauricio Santos President of the Chilean Ergonomics Society, personal communication).

Several major projects focusing on mass product designs have aimed to survey large sections of adult populations. For example, recent projects surveyed the South Korean population (Kim, You, and Kim 2017), European and US adults (Harrison and Robinette 2002) and Chinese adults, and these focused on head/face shape differences (Ball 2009; Du et al. 2008). At present, there is no comprehensive anthropometric dataset for the general adult population in Chile, and the only currently known dimensions for this population are height, weight, neck and waist circumference. Several studies have obtained anthropometric data for workers and described other associated demographics, such as the specific geographic location (Arcaleni 2006; Heineck 2006; Imrhan, Sarder, and Mandahawi 2009), ethnicity (Karmegam et al., 2011; Widyanti et al, 2015), educational level (Huang, Van Poppel, and Lumey 2015), income level (Baynouna et al. 2009; Tao 2014) and many other factors. The data available for Chilean workers, which consider only 19 dimensions, date back to 1995 and it is therefore out date (Apud & Gutiérrez 1997). Additionally, Chile has a rather small manufacturing industry, and clothing, vehicles and tools are mainly only obtained through importation. Currently, managers, designers and engineers do not have the necessary information required to accommodate the entire Chilean adult working population, and this inability is observed in both the purchasing of overseas products and the design of customised products. This lack of data can jeopardise the match between the workers and the workplaces and products used by the workers.

Therefore, the goal of the current study was to collect and describe some anthropometric dimensions of Chilean workers to support the improvement of the products used by this population and thus help prevent health and safety issues. Additionally, this study also compared the anthropometric dimensions of Chilean workers with those of other populations. These comparisons were done, because the databases shared practically the same dimensions (see section 2.6 for further details)

3.2. Methods and Procedure

3.2.1. Sampling technique

Target population: The target population comprised all adult workers registered with Mutual de Seguridad C.Ch.C (work insurance company) in the Valparaíso and Metropolitan Regions in Chile. This population was selected because the research team worked with this organization in a project aiming to conduct an anthropometric survey of Chilean workers.

Sample: The sample consisted of a representative group of workers aged 18 to 65+ years who were assigned to the Mutual de Seguridad C.Ch.C (hereinafter called workers) in the two most populated regions of Chile (Valparaíso and Metropolitana) and distributed in nine branches of economic activity (Agriculture and Fishing, Mining, Manufacturing, Electricity, Construction, Commerce, Transport and Communications, Financial Services, and Communal and Personal Services). For each region, a stratified sampling plan based on economic activity was applied using clusters consisting of a group of 20 workers. To calculate the number of clusters in the sample, $p = 0.5$ was selected, which corresponds to the proportion of workers with anthropometric measures outside the usual ranges. This proportion gives the maximum sample size or number of clusters that should be selected from the population in each region weighted by economic activity. The estimated error was set to 0.04. To determine the number of clusters in the sample for each of the regions, data on the number of average monthly workers and weightings by economic activity were used. Although the number of clusters per region is in accordance with the established sampling plan, for the Metropolitan Region it was decided to double the number of clusters, due to the magnitude of the number of workers in it. For approximation purposes, in all cases where the number of clusters corresponded to a number with a decimal, it was approximated to the next upper integer.

In statistical terms, and for purposes of estimating the parameters corresponding to the different variables to be measured in this study, it was proposed that if the population from which the samples are extracted is not normal, the sample size should be greater or equal to 30, so in this study, for each region, in economic activities where the sampling method resulted in working with one conglomerate, two will be considered, which will produce a sample of 40 workers for that particular cluster. The estimated samples of workers for the Valparaiso and Metropolitan regions were fixed to 760 and 1,320, respectively. In addition, considering the gender distribution in Mutual de Seguridad C.Ch.C, the final estimated sample included 1,493 (71.8%) men and 587 (28.2%) women.

Because this sample was selected with the aim of designing different products and spaces for Chilean workers (workplaces, tools, furniture, etc.), the estimated sample was also tested using the principles defined in ISO 15535 (ISO 2012). As such, the minimum number of randomly sampled subjects, N, needed to ensure that the database's 5^{th} and 95^{th} percentiles estimated the true population's 5^{th} and 95^{th} percentiles with 95% confidence. The percentage of relative accuracy was calculated using the following formula (ISO 2012):

$$N = \left(\frac{1{,}96 \times CV}{\alpha}\right)^2 \times 1{,}534^2$$

where a CV (coefficient of variation) value of 16 was considered for this study because this is the higher CV (abdominal depth) obtained in a previous Chilean anthropometric study, which measured workers aged 17 to 60 years (Apud and Gutiérrez 1997), and α (percentage of relative accuracy desired) was set to 2%, as previously described by Lee et al. (2013).

$$N = \left(\frac{1{,}96 \times 16}{2}\right)^2 \times 1{,}534^2 = 578$$

3.2.2. Procedure before data collection

3.2.2.1. Training

The measurement process was conducted by two survey teams, and each team was composed of three individuals, namely, a measurer, a data recorder and an organizer. The measurer was in charge of taking the measures, the data recorder entered the data on a computer, and the organizer was responsible for accommodating the subjects to ensure that the standard measuring postures were achieved. Before the survey was initiated, the measurement teams underwent a one-week training session, which included a discussion of the theoretical approach used for anthropometric measurements and practical instructions. The training sessions were delivered by two physical therapists with experience in ergonomics and anthropometric data collection. Both teams spent a minimum of 24 hours practising the measurements to ensure high consistency between the measurers.

3.2.2.2. Intra- and inter-reliability

At the end of the training session, a sample of 25 volunteers was measured twice by the two measurers, and both the inter- and intra-measurer reliabilities were evaluated using the "two-way mixed" and "absolute agreement" Intraclass Correlation Coefficient (ICC) models. The correlations were interpreted according to the ranges suggested by Portney and Watkins (2008): ICC≥0.50 was interpreted as moderate, and ICC≥0.75 was interpreted as strong. The results shown in Table 3.1 demonstrate that the measurers exhibited strong inter- and intra-reliability values, with the exception of two dimensions that presented moderate intra-reliability (elbow grip length for measurer 1 and elbow height sitting for measurer 2).

Table 3.1. Intra and Inter-measurer reliability (ICC)

	Anthropometric dimension	Intra-measurer reliability Measurer 1	Intra-measurer reliability Measurer 2	Inter-measurers reliability
1	Weight	0.999	0.997	0.990
2	Stature	0.999	0.996	0.984
3	Body mass index (unit)	--	--	--
4	Eye height	--	--	--
5	Shoulder height	--	--	--
6	Elbow height	--	--	--
7	Knuckle height	0.980	0.983	0.970
8	Sitting height	0.951	0.936	0.937
9	Eye height sitting	0.788	0.898	0.782
10	Shoulder height sitting	0.941	0.912	0.930
11	Subscapular height	0.947	0.885	0.909
12	Grip reach; forward reach	0.941	0.923	0.950
13	Elbow grip length	0.737	0.943	0.901
14	Shoulder-elbow length	--	--	--
15	Elbow height sitting	0.901	0.703	0.793
16	Abdominal depth	0.953	0.949	0.942
17	Thigh Clearance	0.864	0.866	0.879
18	Buttock-Popliteal Length	0.910	0.789	0.878
19	Buttock-knee length	0.977	0.895	0.956
20	Knee height	0.836	0.986	0.959
21	Popliteal height	0.940	0.967	0.929
22	Shoulder (bideltoid) breadth	0.974	0.982	0.975
23	Elbow to elbow breadth	0.952	0.937	0.948
24	Hip breadth	0.781	0.761	0.784
25	Hand length	0.951	0.929	0.875
26	Hand Breadth (across thumb)	0.963	0.882	0.924
27	Hand Breadth (metacarpal)	0.973	0.946	0.939
28	Foot breadth	0.890	0.839	0.867
29	Foot length	0.975	0.976	0.968
30	Head circumference	0.992	0.995	0.992
31	Neck circumference	0.951	0.929	0.875
32	Waist circumference	0.963	0.882	0.924

3.2.3. Data collection

3.2.3.1. Anthropometric measurements

The anthropometric measures described in Table 3.2 and Figures 3.1, 3.2 and 3.3 were considered to define a large number of dimensions for different design purposes (ISO, 2008).

Table 3.2. Anthropometric measurements considered in the study

		Anthropometric measurements	Definition
Standing	1	Weight	total mass (weight) of the body
	2	Stature	vertical distance between the floor and the top of the head. and measured with the subject erect and looking straight ahead (Frankfort plane).
	3	Body mass index (unit)*	calculated through Weight (kg)/ Stature^2 (m^2).
	4	Eye height*	calculated through (Stature – (Sitting height – Eye height sitting)).
	5	Shoulder height*	calculated through (Stature – (Sitting height – Shoulder height sitting)).
	6	Elbow height*	calculated through (Stature – (Sitting height – Elbow height sitting)).
	7	Knuckle height	vertical distance from the floor to metacarpal III (i.e. the knuckle of the middle finger).
Sitting	8	Sitting height	vertical distance between subject's seated surface to the top of the head. And measured with the subject erect and looking straight ahead (Frankfort plane).
	9	Eye height sitting	vertical distance between the sitting surface to the inner canthus (corner) of the eye (head in Frankfurt plane).
	10	Shoulder height sitting	vertical distance from subject's seated surface to the acromion.
	11	Subscapular height	vertical distance from the lowest point (inferior angle) of the scapula to the subject's seated surface.
	12	Grip reach; Forward reach	horizontal distance from a vertical surface to the grip axis of the hand while the subject leans both shoulder blades against the vertical surface.
	13	Elbow grip length	horizontal distance from back of the upper arm (at the elbow) to grip axis, with elbow bent at right angles.
	14	Shoulder-elbow length*	calculated through (Shoulder height sitting – Elbow height sitting).
	15	Elbow height sitting	taken with a 90° angle elbow flexion. As the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
	16	Abdominal depth	maximum horizontal distance from the vertical reference plane to the front of the abdomen in the standard sitting position.
	17	Thigh Clearance	vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
	18	Buttock-Popliteal Length	horizontal distance from the popliteal surface to the rearmost point of the buttock.
	19	Buttock-knee length	horizontal distance from the foremost point of the knee-cap to the rearmost point of the buttock.
	20	Knee height	vertical distance from the floor or footrest to the highest point of the superior border of the patella.
	21	Popliteal height	vertical distance from the floor or footrest to the posterior surface of the knee (popliteal surface).
	22	Shoulder (bideltoid) breadth	distance across the maximum lateral protrusions of the right and left deltoid muscles.
	23	Elbow to elbow breadth	maximum horizontal breadth across the elbows.

	24	Hip breadth	horizontal distance measured in the widest point of the hip in the sitting position
Hand & Foot	25	Hand length	perpendicular distance from a line drawn between the styloid processes to the tip of the middle finger.
	26	Hand Breadth (across thumb)	projected distance between radial and ulnar at the level of the metacarpal-phalangeal joint of digit 1 to the ulnar side of the hand. second to the fifth metacarpal.
	27	Hand Breadth (metacarpal)	projected distance between radial and ulnar metacarpals at the level of the metacarpal heads from the second to the fifth metacarpal.
	28	Foot breadth	maximum distance between medial and lateral surfaces of the foot perpendicular to the longitudinal axis of the foot.
	29	Foot length	maximum distance from rear of the heel to tip of the longest (first or second) toe, measured parallel to the longitudinal axis of the foot.
Standing	30	Head circumference	maximum, approximately horizontal, circumference of head measured above the glabella and crossing the rearmost point of the skull.
	31	Neck circumference	circumference of neck at a point just below the bulge at the thyroid cartilage.
	32	Waist circumference	circumference of trunk at a level midway between the lowest ribs and the upper iliac crest.

*Calculated from different anthropometrics measurements

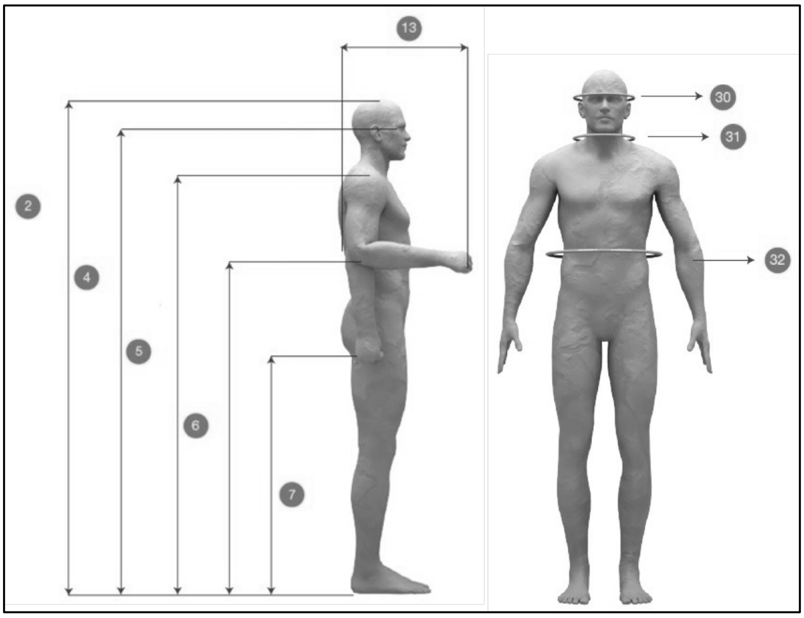

Figure 3.1. Anthropometric measurements gathered in standing position

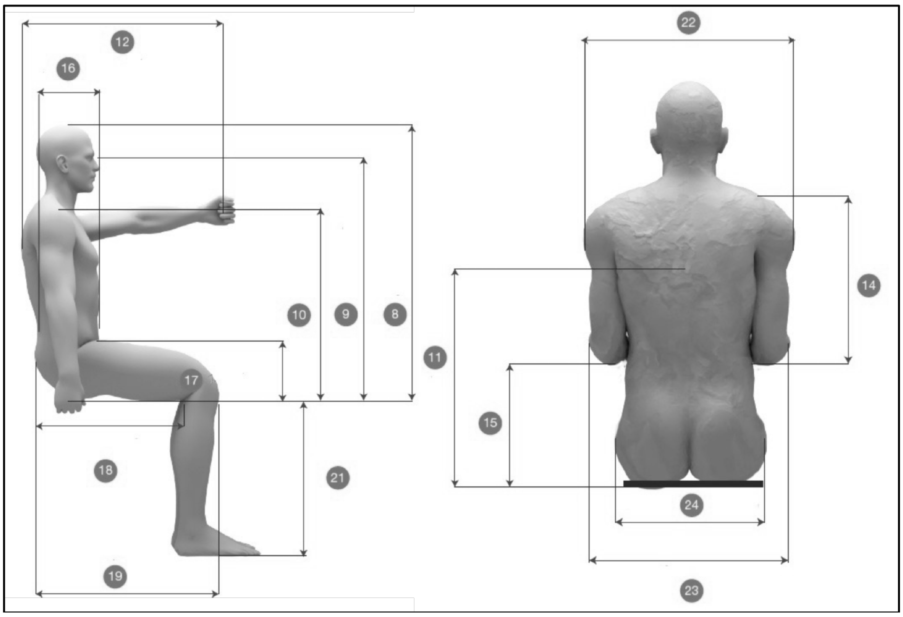

Figure 3.2. Anthropometric measurements gathered in sitting position

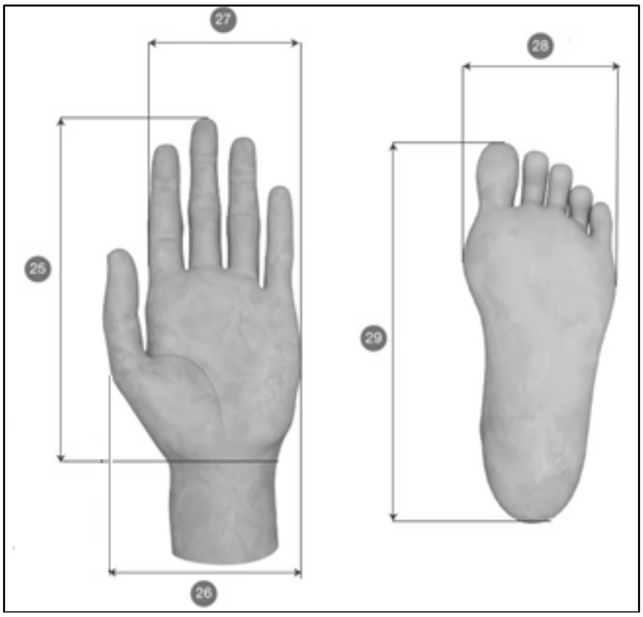

Figure 3.3. Anthropometric measurements gathered on hands and feet

3.2.3.2. Instruments

To reduce measurement error, both teams used the same instruments. Most of the measures were obtained using a Harpenden anthropometer (Holtain Ltd®., Crymych, UK), and the body circumferences were measured with metallic measuring tape (Rosscraft®). In addition, the weight and stature of the subjects were measured with a Seca 700 mechanical column scale and stadiometer, respectively.

Additionally, to ensure a standardized posture among the subjects, a height-adjustable chair with a horizontal surface and an adjustable footrest was used.

3.2.3.3. Data collection procedure

The data collection was carried out from April 2016 to September 2016, and all the data were recorded in an Excel spreadsheet, which allowed for the detection of unusual values. The standard procedure proposed by ISO 7250-1 (2008) was followed in the collection of the anthropometric measurements. The procedure indicates that the anthropometric measures need to be collected from the right side of the subjects' body while they are sitting in an erect position on a chair with a horizontal surface with their legs flexed at a 90° angle and with their feet flat on the ground. During the measurement process, the subjects wore no shoes and light clothing (shorts and t-shirts).

Additionally, to ensure data quality and reduce measurement error, at approximately 6-minute intervals during the measurement process, the recorder and the measurer checked the calibration of the anthropometer. If the anthropometer was out of calibration, it was recalibrated, and if the worker agreed, he/she went through the measurement process again. If the worker opted to not undergo re-measurement, all their information was deleted. In addition, the measurement error was tested every month with part of the sample used during training sessions.

3.2.4. Assessment of data before analysis

After data collection, the following steps were performed because some errors, such as adding the wrong anthropometer extension, changing the digit's order, adding an extra zero or a misplacing a comma, can be introduced during the collection process:

- Observation of the mean, minimum, and maximum values. As proposed in ISO 15535, the objective is to identify data outside the interval defined by the mean ± 3 standard deviations;
- Subtraction of different measurements because it is not physically possible that the values of the following calculations present negative values (e.g., if

the participant height is smaller than his/her eye height, it can be assumed that at least one of the measurements is erroneous). The following subtractions were performed: sitting height - eye height sitting, eye height sitting - shoulder height sitting, shoulder height sitting - subscapular height, subscapular height - elbow height sitting, grip reach forward reach - elbow grip length, buttock-knee length - buttock-popliteal length, knee height - popliteal height, and hand breadth (across thumb) - hand breadth (metacarpal);

- Observations of scatter plot graphics (stratified by gender, stature and weight) with the other variables (see the example shown in Figure 3.4). The same procedure was also followed for other variables, such as hip breadth with BMI, abdominal depth with BMI, grip reach forward reach with elbow grip length, grip reach forward reach with elbow grip length, and buttock-knee length with buttock-popliteal length; and
- For borderline subjects, a percentile profile was performed. A percentile profile gives an overview of a series of percentile values of a given subject and emphasizes the variation within the subject, e.g. a subject with a high percentile in stature is expected to follow the same trend in others vertical dimensions.

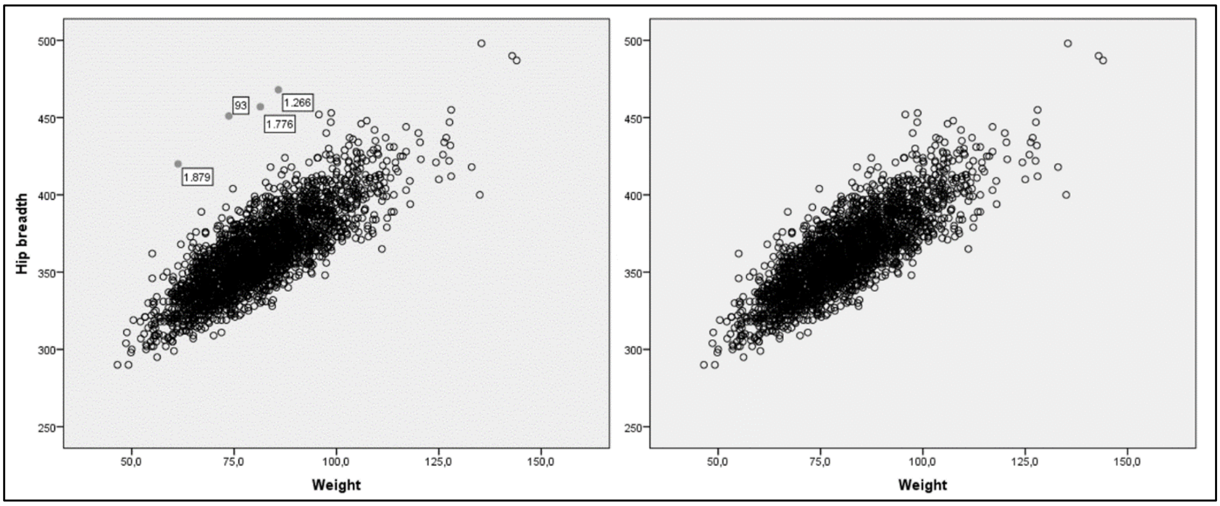

Figure 3.4. Example of observations of scatter plot graphics

In the left graph, there are four numbers (subjects) that presented unusual values, after evaluation, the cause was not identifiable, and the entire data of the four subjects were not considered in this study (right graph)

3.2.5. Ethics

The data collection process was approved by the Committee of Ethics at Chilean Construction Chamber (Camara Chilena de la Construcción). Written consent was obtained from the workers before the measurement procedures were started.

3.2.6. Statistical Analysis

All anthropometric data were analysed using MS Excel and SPSS (v24.0, SPSS Inc., Chicago, IL, USA). An independent t-test (with a 95% confidence interval) was performed to examine the differences in measurements between genders. Additionally, an independent t-test was performed to compare the differences between the Chilean anthropometric data and data from the ISO 7250-2, specifically, data from South Korea, the Netherlands and the United States because these databases contain practically the same 32 dimensions collected in this study. In addition, the latter comparisons can highlight the magnitude of the variation and thus stress the importance of using appropriate data when designing products and workplaces aimed at Chilean workers.

3.3. Results

3.3.1. Sample

After checking the data for errors and performing the post-elimination process (Table 3.3), a total sample of 2946 volunteer workers was obtained (not randomly selected), which exceeded the estimated sample of 2080 workers. As shown in Table 3.4, this surplus in the sample was mainly due to a surplus from male workers (853 additional male workers; 2346 obtained versus 1493 estimated), and there was a smaller surplus of female workers in the sample compared with that of males (600 obtained versus 587 estimated). Additionally, as indicated in Table 3.4, 80% of the total sample was between 20-49 years of age, whereas the second largest proportion of the sample (18%) consisted of the age group of 50-69 years, and the remaining 2% represented workers aged 18-19 and 70-79 years. This finding is also shown in Table 3.5, which shows that the average ages of female and male workers were 35.4 (SD: 12.5) and 38.3 (SD: 11.6) years, respectively. Although these phenomena will be further addressed in the Discussion section, these differences mainly originate from our access to the various types of employment related to gender and age in Chile.

Table 3.3. Results from the quality data process

	Male	Female	Total
Total collected sample	2373	601	2974
Data were corrected due:			
adding the wrong anthropometer extension	5	2	7
changing the number order	14	7	21
adding an extra zero or misplaced comma	4	1	5
place dot by comma	4	2	6
Subjects deleted	27	1	28
Final Sample	2346 (79.6%)	600 (20.4%)	2946

Table 3.4. Study sample characterization

Gender	Age group (years old)							TOTAL	
	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 to 79	Real	Estimated
Female	8	256	141	102	66	20	7	600	587
Male	17	634	683	544	374	87	7	2346	1493
TOTAL	25	890	824	646	440	107	14	2946	2080

3.3.2. Stature, weight and nutritional status

As shown in Table 3.5, the average statures of females and males were 1593 mm (SD: 12.5) and 1710 mm (SD: 65), respectively, and the average weights of females and males were 66.9 kg (SD: 12) and 81.4 kg (SD: 13.1), respectively. Expectedly, these general indicators are similar to worldwide trends, which indicate that men are taller and heavier than women. A particular finding was that the average BMIs of the two genders were quite similar, and both fell into the overweight category (25 ≥ BMI ≤ 29,9) (WHO 2000), showing that Chilean workers are following the global epidemic of being overweight (Heineck 2006; Gordon and Bradtmiller 2012; Tomkinson, Clark, and Blanchonette 2010; Cole 2003). The findings are similar to those of previous studies on Chilean workers, such as the study developed in 2008, which considered a sample size of 1,036 women and 709 men and showed that 60% of the sample was overweight and that more than 30% of the sample was obese (Ratner et al. 2008). Other studies on Chilean workers focusing on mining and construction workers obtained similar results: 96% of mining workers and 82% of construction workers were either overweight or obese (Caichac et al., 2013; Salinas et al., 2014). The average BMI of Chilean workers is not surprising because the recent National Health Survey (Encuesta Nacional de Salud) from 2017 showed that 39.8%, 31.2% and 3.2% of the population is overweight, obese and morbidly obese, respectively (MINSAL 2017).

Table 3.5. Anthropometric data collected in the present study

	Variables (mm)	Female (N=600)					Male (N=2,346)				
		Mean	SD	P5	P50	P95	Mean	SD	P5	P50	P95
	Age (years)**	35.4	12.5	20.2	32.1	59.1	38.3	11.6	22.2	36.4	58.4
1	Weight (Kgs)**	66.9	12.0	50.5	65.5	89.0	81.4	13.1	62.0	80.5	104.5
2	Stature**	1593.0	61.0	1488.0	1595.0	1692.0	1710.0	65.0	1606.0	1710.0	1820.0
3	Body mass index (unit)**	26.4	4.7	20.4	25.6	35.1	27.8	3.9	21.9	27.5	34.7
4	Eye height**	1488.3	60.4	1386.0	1488.5	1585.0	1600.7	63.8	1499.0	1599.0	1709.0
5	Shoulder height**	1316.1	55.8	1221.1	1316.0	1407.0	1416.2	59.9	1320.0	1414.0	1518.0
6	Elbow height**	977.3	46.3	902.0	977.0	1053.9	1041.9	48.3	965.0	1040.0	1123.0
7	Knuckle height**	711.4	34.8	656.1	709.0	771.0	758.8	38.3	699.0	757.0	824.0
8	Sitting height**	859.9	32.4	804.2	858.0	918.0	912.3	35.0	855.0	912.0	972.0
9	Eye height sitting**	755.0	32.0	700.1	755.0	810.0	803.5	33.3	750.4	803.0	862.0
10	Shoulder height sitting**	582.8	26.5	540.1	584.0	629.0	619.0	28.5	573.0	618.0	666.0
11	Subscapular height**	441.1	26.2	398.1	440.5	485.0	460.6	27.2	417.0	460.0	505.0
12	Grip reach; forward reach**	681.5	36.1	625.1	680.0	749.0	740.9	39.0	680.4	739.0	807.0
13	Elbow grip length**	311.4	17.7	282.0	312.0	341.0	340.3	18.5	311.0	340.0	371.0
14	Shoulder-elbow length**	338.8	20.0	304.0	339.0	371.0	374.4	23.2	338.0	374.0	413.0
15	Elbow height sitting	244.0	24.8	205.1	243.0	285.0	244.6	24.4	206.4	244.0	286.0
16	Abdominal depth**	238.2	49.4	177.0	229.0	334.0	267.6	39.4	206.0	266.0	335.0
17	Thigh Clearance**	151.5	15.9	129.0	151.0	180.0	165.4	14.9	142.0	165.0	191.0
18	Buttock-Popliteal Length**	479.0	24.6	437.1	479.0	522.0	496.5	24.6	457.0	496.0	537.0
19	Buttock-knee length**	559.8	26.6	516.0	560.0	606.0	590.4	27.5	548.0	590.0	637.0
20	Knee height**	482.8	23.5	445.0	483.0	524.0	522.6	25.7	481.0	522.0	567.0
21	Popliteal height**	403.8	21.3	370.0	405.0	440.0	436.2	23.2	399.0	436.0	474.0
22	Shoulder (bideltoid) breadth**	431.8	34.2	386.0	426.0	497.9	475.0	30.1	429.0	474.0	528.0
23	Elbow to elbow breadth**	435.2	54.5	353.1	429.5	526.0	487.7	47.8	409.0	488.0	563.0
24	Hip breadth**	390.7	32.0	344.0	389.0	448.0	362.5	26.1	323.0	361.0	408.0

25	Hand length**	165.9	8.6	152.0	166.0	180.0	181.1	9.4	167.0	181.0	197.0
26	Hand Breadth (across thumb)**	87.6	5.0	80.0	88.0	96.0	100.9	5.4	92.0	101.0	110.0
27	Hand Breadth (metacarpal)**	74.9	4.1	69.0	75.0	82.0	85.1	4.5	78.0	85.0	93.0
28	Foot breadth**	88.6	5.1	81.0	88.0	97.0	97.2	5.3	89.0	97.0	106.0
29	Foot length**	231.4	11.0	214.1	231.0	252.0	254.0	11.8	235.0	254.0	273.0
30	Head circumference**	549.0	16.0	524.0	549.0	576.0	567.0	16.0	540.0	567.0	593.0
31	Neck circumference**	332.0	27.0	295.0	328.0	380.0	395.0	28.0	351.0	394.0	443.0
32	Waist circumference**	808.0	112.0	655.0	787.0	102.0	925.0	95.0	777.0	925.0	1080.0

**$p<0.01$

3.3.3. Segmental dimensions and perimeters

As shown in Table 3.5, the segmental dimensions and perimeters of males were greater than those of females, with the exception of hip breadth, and the homogeneity of the dimensions expressed by the standard deviations was quite diverse. However, some dimensions exhibited a greater dispersion in both genders: such as eye height (F: 60.4 mm - M: 63.8 mm), shoulder height (F: 55.8 mm - M: 59.9 mm), elbow height (F: 46.3 mm - M: 48.3 mm), abdominal depth (F: 49.4 mm - M: 39.4 mm), elbow to elbow breadth (F: 54.5 mm - M: 47.8 mm) and waist circumference (F: 112.0 mm - M: 95.0 mm). The dispersion of the aforementioned dimensions can have an impact on some designs, as will be debated in the Discussion section of this paper. It is worth noting that all of the anthropometric dimensions, with the exception of elbow height sitting, exhibited significant differences between male and female workers.

3.3.4. Comparison with anthropometric data from South Korea, the Netherlands and the United States.

A comparison with the data presented in ISO 7250-2 was performed to observe the differences between Chile and South Korea, the USA and the Netherlands. These populations were selected to compare the Chilean population with populations from three different continents but mainly because the available data from these populations included almost the same 32 dimensions investigated in the current study. As shown in Table 3.6, in general, Chilean adults are significantly smaller than adults from the USA and the Netherlands but are larger than South Koreans. However, a few exceptions to this trend were observed. For example, compared with the Netherlands, only the thigh clearance of the Chilean populations was larger, and this finding was obtained for both genders (Chile F: 151.5 mm - M: 1654 mm vs. the Netherlands F: 146.9 mm - M: 146.2 mm, $p<0.01$); in addition, the shoulder breadth of Chilean males was greater than that of Dutch males, but this different was not statistically significant (Chile M: 475.0 mm vs. the Netherlands M: 472.5 mm). As shown in Table 3.6, compared with the USA, the Chilean female and male populations had larger values for the following dimensions: shoulder height sitting (Chile F: 582.8 mm - M: 619.0 mm vs. USA F:

567.5 mm - M: 601.9 mm, $p<0.01$) and elbow height sitting (Chile F: 244.0 mm - M: 244.6 mm vs. USA F: 236.9 mm - M: 239.1 mm, $p<0.01$). Chilean females presented larger values than American females exclusively for the sitting height (Chile F: 864.1 mm vs. USA F: 859.9 mm, $p<0.05$) and shoulder breadth (Chile F: 431.8 mm vs. USA F: 431.4 mm), whereas Chilean males only had higher values for eye height sitting (Chile M: 803.5 mm vs. USA M: 803.2 mm); and the differences in shoulder height between the female populations and in eye height sitting between the male populations were not statistically significant. The South Koreans are generally smaller than the Chileans, with some exceptions. For example, South Koreans females and males have larger values for elbow height sitting (Chile F: 244.0 mm - M: 244.6 mm vs. Korea F: 246.7 mm - M: 258.3 mm, $p<0.05$ for females and $p<0.01$ for males) and hand length (Chile F: 165.9 mm - M: 181.1 mm vs. Korea F: 174.7 mm - M: 185.8 mm, $p<0.01$). Additionally, as shown in Table 3.6, South Korean females have a larger hand breadth (metacarpal) (Chile F: 74.9 mm vs. Korea F: 76.7 mm, $p<0.01$) and a greater foot breadth than Chilean females (Chile F: 88.6 mm vs. Korea F: 91.8 mm, $p<0.01$). Moreover, South Korean males have higher mean values for foot breadth (Chile M: 97.2 mm vs. Korea M: 99.5 mm, $p<0.01$) and head circumference (Chile M: 567.0 mm vs. Korea M: 571.7 mm, $p<0.01$) than Chilean males, and surprisingly, the average stature of Chilean and South Korean males was practically the same (Chile M: 1710.0 mm vs. Korea M: 1707.6 mm).

Table 3.6 - Comparison of the Chilean anthropometric data with other populations

	Variables (mm)	Female											Male										
		Chile (N=600)		Netherlands			Korea			United States			Chile (N=2346)		Netherlands			Korea			United States		
		Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
	Age (years)	35.4	12.5	698	38.6**	12.8	2614	34.1**	12.1	1262	39.8**	12.1	38.3	11.6	564	38.5	13.4	2613	34.0**	12.2	1121	39.3*	11.9
1	Weight (kgs)	66.9	12.0	679	73.9**	15.8	2612	56.1**	7.8	1261	69.6**	19.9	81.4	13.1	595	85.6**	17.3	2611	70.1**	9.7	1119	83.2**	17.4
2	Stature	1593.0	61.0	679	1672.3**	79.0	2614	1579.0**	54.8	1261	1637.9**	78.4	1710.0	65.0	593	1808.1**	92.8	2613	1707.6	61.3	1119	1766.6**	80.6
3	Body mass index (unit)	26.4	4.7	--	--	--	--	--	--		--	--	27.8	3.9	--	--	--	--	--	--	--	--	--
4	Eye height	1488.3	60.4	691	1569.1**	73.2	2613	1469.3**	52.5	--	--	--	1600.7	63.8	558	1695.9**	84.4	2613	1591.2**	59.9	--	--	--
5	Shoulder height	1316.1	55.8	587	1361.5**	70.5	2613	1285.6**	47.8	1257	1342.5**	69.6	1416.2	59.9	542	1476.4**	81.3	2612	1392.1**	53.4	1113	1445.2**	76.4
6	Elbow height	977.3	46.3	685	1040.1**	54.4	2613	967.3**	38.2	--	--	--	1041.9	48.3	562	1122.6**	66.1	2613	1044.3	42.4	--	--	--
7	Knuckle height	711.4	34.8	207	747.9**	40.0	2611	708.7	33.5	--	--	--	758.8	38.3	588	804.0**	46.5	2609	757.6	35.5	--	--	--
8	Sitting height	859.9	32.4	677	884.6**	38.1	2614	857.8	29.2	1260	864.1*	38.7	912.3	35.0	589	941.8**	42.5	2612	921.5**	32.2	1119	920.6**	42.8
9	Eye height sitting	755.0	32.0	676	774.5**	35.8	2613	747.6**	27.8	1260	754.5	36.6	803.5	33.3	594	825.4**	39.7	2613	805.7*	31.3	1119	803.2	41.5
10	Shoulder height sitting	582.8	26.5	675	589.5**	33.2	2613	556.7**	24.1	1261	567.5**	31.6	619.0	28.5	590	629.9**	36.0	2613	595.9**	26.6	1119	601.9**	37.8
11	Subscapular height	441.1	26.2	--	--	--	--	--	--		--	--	460.6	27.2	--	--	--	--	--	--	--	--	--
12	Grip reach; forward reach	681.5	36.1	207	684.9	35.3	2613	659.2**	30.1	--	--	--	740.9	39.0	181	751.5**	44.4	2608	698.8**	42.7	--	--	--
13	Elbow grip length	311.4	17.7	207	322.1**	17.0	2611	301.7**	16.3	--	--	--	340.3	18.5	181	355.5**	20.7	2610	327.3**	17.1	--	--	--
14	Shoulder-elbow length	338.8	20.0	683	342.8**	20.0	2613	307.3**	15.2	--	--	--	374.4	23.2	555	376.5	22.8	2612	337.8**	15.6	--	--	--
15	Elbow height sitting	244.0	24.8	664	248.0**	27.0	2612	246.7*	22.1	1260	236.9**	29.8	244.6	24.4	590	254.6**	28.3	2612	258.3**	23.9	1119	239.1**	35.1
16	Abdominal depth	238.2	49.4	207	276.5**	45.9	2612	215.0**	34.3	--	--	--	267.6	39.4	181	283.5**	40.3	2603	232.8**	32.2	--	--	--
17	Thigh Clearance	151.5	15.9	207	146.9**	14.6	2611	137.3**	12.9	--	--	--	165.4	14.9	181	146.2**	14.5	2613	153.0**	15.9	--	--	--
18	Buttock-Popliteal Length	479.0	24.6	207	497.6**	27.5	2614	445.4**	22.4	--	--	--	496.5	24.6	181	508.4**	29.3	2613	467.1**	26.6	--	--	--
19	Buttock-knee length	559.8	26.6	678	608.1**	31.2	2614	541.4**	24.6	1260	587.7**	40.5	590.4	27.5	589	636.2**	37.4	2613	570.6**	26.3	1119	614**	36.5
20	Knee height	482.8	23.5	664	510.7**	28.8	2752	474.9**	21.8	1261	508.5**	31.3	522.6	25.7	584	557.1**	36.0	2766	510.2**	24.6	1119	558**	32.1
21	Popliteal height	403.8	21.3	207	436.1**	26.7	2614	368.8**	21.4	--	--	--	436.2	23.2	181	485.8**	30.2	2612	399.6**	22.2	--	--	--
22	Shoulder (bideltoid) breadth	431.8	34.2	678	433.2	31.6	2611	418.1**	23.7	1261	431.4	39.1	475.0	30.1	590	472.5	30.4	2612	465.6**	24.6	1119	490.4**	37.8
23	Elbow to elbow breadth	435.2	54.5	--	--	--	2613	420.9**	41.4	--	--	--	487.7	47.8	--	--	--	2611	475.0**	44.9	--	--	--
24	Hip breadth	390.7	32.0	677	418.9**	38.3	2614	348.8**	20.4	1259	410.4**	52.9	362.5	26.1	589	383.1**	29.8	262	347.7**	21.0	1117	376.3**	38.1
25	Hand length	165.9	8.6	679	184.5**	9.9	2613	174.7**	8.0	1260	181.7**	12.1	181.1	9.4	595	202.8**	11.2	2611	185.8**	8.3	1119	202**	12
26	Hand Breadth (across thumb)	87.6	5.0	--	--	--	--	--	--	--	--	--	100.9	5.4	--	--	--	--	--	--	--	--	--

27	Hand Breadth (metacarpal)	74.9	4.1	--	--	--	2613	76.7**	4.1	--	--	--	85.1	4.5	--	--	--	2612	83.6**	4.2	--	--	--
28	Foot breadth	88.6	5.1	584	94.9**	6.7	2611	91.8**	5.5	1258	92.8**	8.5	97.2	5.3	542	103.9**	7.4	2611	99.5**	5.8	1114	104.1**	8
29	Foot length	231.4	11.0	679	243.2**	13.0	2613	230.0**	9.7	1261	239.1**	14.2	254.0	11.8	594	268.9**	15.9	2612	250.6**	11.4	1119	266.7**	15.4
30	Head circumference	549.0	16.0	676	550.3	15.4	2612	547.9	14.3	1260	552**	18.1	567.0	16.0	589	574.3**	18.2	2611	571.7**	15.5	1119	577.1**	18.1
31	Neck circumference	332.0	27.0	--	--	--	--	--	--		--	--	395.0	28.0	--	--	--	2613	376.8**	22.0	--	--	--
32	Waist circumference	808.0	112.0	--	--	--	2614	730.7**	88.0	--	--	--	925.0	95.0	--	--	--	2613	821.0**	84.4	--	--	--

* p<0.05 ** p<0.01

3.4. Discussion

The findings regarding the mean sample age are likely explained by the national situation in Chile and the demographics of the country. As mentioned in the Results section, the actual sample numbers for both genders met and even exceeded the estimated sample sizes, and this surplus was obtained by a larger contribution of male workers to the sample. This finding could be explained by the fact that the participation of women in the investigated types of work is much lower than that of men in Chile. According to the Chilean National Statistics Institute (INE), the employment participation rate of women is 48.3%, whereas that of men is 72%, and this participation rate of women is quite low compared to other Organization for Economic Co-operation and Development (OECD) countries, such as Nordic nations, where the women's participation rate is approximately 65% (INE 2015).

The age ranges in the sample included in the current study are mainly explained by the reality of the Chilean workplace. The sample matches the target population and shows an age distribution similar to that of the national working population. In fact, INE reports that the lowest participation rates for both genders are obtained for the age range of 65+ years (F: 12.9% - M: 35%), followed by the age range of 15-24 years (F: 25% - M: 35%). Hence, a lower participation rate was obtained for those age ranges; therefore, the study sample has an age distribution that is similar to that of Chilean workers. Additionally, women have lower access to formal employment and participate less in worker insurance activities, where the samples were collected (INE, 2015). It is worth mentioning that the legal retirement ages in Chile for women and men are 60 and 65 years, respectively; however, the actual retirement ages of women and men are 70 and 69 years, respectively, showing that Chilean women work for a longer period of time within the OECD countries (OECD 2013). The main reason for this discrepancy is that pensions are often very low, and as a result, older adults need to keep working to increase their pensions or often engage in informal work, which could explain why the study had fewer older participants (OECD, 2013). Additionally, according to the OECD, the Chilean reality is unusual because the effective exit age from the work market for both genders is inferior to the retirement age in 22 out of the 34 OECD countries. It would be interesting to repeat a similar anthropometric survey of Chilean workers ten years from now to observe how older adults form part of the formal active working population. The Chilean population is getting older; in fact, the last national demographic survey (CASEN, 2015) showed that the percentage of citizens aged 65+ years is 17.5% (Ministerio de Desarollo Social 2016), which indicates that according to the UN criteria, Chile is undergoing an advanced ageing process. According to projections, by 2025, the number of Chileans between 0 and 14 years will equal the number of Chileans aged over 65 years (CEPAL 2012), and this latter group will definitely have an impact on the workforce composition, where the ageing factor presents more challenges when attempting to accommodate workers to their jobs. For example, musculoskeletal disorders are one of the main causes of work disability among older workers (Ilmarinen 2006; Palmer and Goodson 2015), and there is evidence showing that anticipating the cognitive and physical limitations of ageing is an effective way to prevent complications (Silverstein 2008). When used properly, anthropometrics might play a very relevant role in preventing musculoskeletal disorders by creating less harmful workplace and product designs (Kushwaha and Kane 2016; Spyropoulos et al. 2007).

Another relevant consideration is that the current study sample included only Chilean born workers, thus future research should also address how migration may affect the anthropometrics of Chilean workers. Migration has been highly associated with an ageing population and improvements in living standards (Fougère et al. 2004). Historically, Chile has had a rather homogeneous ethnicity, composed of Spanish and Amerindian populations, as confirmed by the first (and only) national genetic study (Chilegenómico), which found no ethnic differences among 3200 Chileans from eight cities across the north, centre and south of Chile (Chilegenómico, 2015). In fact, the study found that, on average, Chilean genetics are 51% European, 44% Amerindian and 3% African. The data collection of the current study was conducted during 2016 and was thus performed before the most recent migrant "wave" that has arrived in Chile, especially those migrants from Haiti, which are mainly of African ethnicity (Rojas and Silva 2016). As noted in an El Mercurio Newspaper article on 10 April 2018, during a 2017 migration peak, 100.000 Haitian migrants entered the country with a tourist visa, but 98% of them changed their visa status to a work visa or temporary visa. This phenomenon was due in part to Chilean migration policies, and this work-related migration situation is unprecedented for Chile but is quite common in other countries, including both developed and developing countries. In fact, anthropometric studies have accounted for ethnic differences because these characteristics can definitively have an impact on design and safety. For example, worker differentiations by ethnic group can be detected in Malaysia (Karmegam et al. 2011), Iran (Sadeghi, Bahrami, and Joneidi Jafari 2014; Sadeghi, Mazloumi, and Kazemi 2015), Indonesia (Widyanti et al. 2015; Wibowo, Soni, and Salokhe 2013), Bangladesh (Akhter et al. 2010), the UK (Stirling 2005), the US (Hsiao et al. 2014; Yang, Shen, and Wu 2007; Guan et al. 2015), East Asia (Schwekendiek and Jun 2010; Lin, Wang, and Wang 2004) and China (Yang, Shen, and Wu 2007; Ball 2009). Migrants in Chile were initially employed in informal jobs but are currently taking part in many formal ones; thus, further studies should address any changes in the anthropometrics of Chilean worker by focusing on and differentiating based on ethnicity.

The Chilean worker database was created for design purposes. The tables presented in this study should be used to produce and assess the suitability of any design aimed at Chilean workers. The current tables constitute the most up-to-date and complete datasets of Chilean worker anthropometrics and include 32 dimensions for both female and male workers.

It is interesting to note that the dispersion of some dimensions, such as eye height, shoulder height, elbow height, abdominal depth, elbow-to-elbow breadth and waist circumference, was high in both genders. This dispersion implies the existence of clear heterogeneity, which indicates that designs that use the previously stated dimensions will be more difficult to match with a wider target population. For instance, if considering elbow height and shoulder height, which are used as criteria to set proper manual handling heights (assembly lines/storage) (Pheasant and Haslegrave 2006), fitting a non-adjustable design to the majority of the population to a non-adjustable design will be more complex. Similar conclusions can be drawn for all the other dimensions with a high dispersion; for example, the elbow to elbow breadth is used to set forearm supports on various applications, including public transportation, such as airplanes, trains or buses (Molenbroek, Albin, and Vink 2017). This heterogeneity implies that a larger space will be needed to design, for example, adjustable arm rests that could fit the majority of the population (Lee et al. 2013).

In addition to design purposes, the data presented in this study could be used to purchase and import products that currently exist in the market. Chile has little to no industrial production, mainly because the main sources of the country's income are commodities (mining and agriculture). Therefore, a large number of products aimed at Chilean workers are manufactured overseas, mainly China and Europe, and imported, and as a result, high levels of mismatch between the products and Chilean workers are likely to occur. This situation was observed in agricultural farm tractors in Nigeria, where tractors imported from India exhibited a high mismatch with Nigerian workers, resulting in productivity issues (Obi, Ugwuishiwu, and Busayo 2015). Other products that could be properly selected based on the findings of the current study are personal protective equipment (PPE), such as gloves and helmets. It is well known that for PPE to achieve the desired outcome of protecting against different agents, it is necessary to have a good match between the user anthropometrics and the product in question; otherwise, the product can have a reduced protection effect or even produce a fake feeling of protection, leading to more harm than good (Hsiao et al. 2014; Hsiao et al. 2005; Hsiao 2013).

Comparing a population's anthropometrics against those of other countries is common and is mainly performed to observe similarities or differences in order to determine whether a particular population could/should use the same designs as another population. For example, this approach showed differences between US electricity workers and general and military populations (Marklin et al. 2010), among different ethnic groups in Indonesia (Syuaib 2015) and among neighbouring nations, such as Bangladesh, Malaysia, South Thailand and India (Khadem and Islam 2014). The comparison of the anthropometric dimensions of Chilean workers with those of the United States, the Netherlands and South Korea clearly revealed that the measurements are quite different, which reinforces the conclusion that the data presented in this study should be used to accommodate Chilean workers.

The samples included in ISO 7250-2 had similar characteristics regarding age to the sample used in this study: the ages of the sample of South Korean workers, which was collected between 2003 and 2004, ranged from 18 from 60 years, whereas that of the Netherlands sample, which was collected in the period 2003-2004, ranged from 18 to 65 years, and that of the sample of US workers, which was distributed in 10 states as well as Ottawa and Ontario (Canada) and was collected between 1998 and 200, ranged from 18 to 65 years (ISO 7250-2, 2010). The influence of secular trends due to time differences between data collection dates could be a limitation. This trend, however, might not have an impact on the Dutch data because their secular trend has stopped (Schönbeck et al 2013). Even if the times of collection differ from the collection date of the sample included in this study, it is still valuable to pinpoint the differences among population anthropometrics that should be accounted for and periodically addressed to anticipate any possible mismatches between a population's dimensions and designs.

It is worth mentioning that manual measurements were used in this study. This choice was made to reduce costs and because these values are highly accurate if used properly, i.e., if the measurers undergo extensive practice sessions and training and if their intra- and inter-rater errors are measured and corrected accordingly (da Silva, Halpern, and Gordon 2017). Chile currently has no full body 3D scanners; thus, using such a scanner was not an option even though performing 3D scans, which are recommended for assessing biotype and body/head shapes, would have been ideal (Ball 2009; Pandarum, Yu, and Hunter 2011).

Even though the current study included a very large sample and developed an extensive database, it should be acknowledged that the findings are somewhat limited by the fact that these figures are based on the analysis of only two regions of Chile (the two most populated ones). Despite these limitations, there was no up-to-date dataset of Chilean workers prior to this study. The newly created database will allow engineers and designers to develop protective equipment, workplaces, and products in a more precise manner. The tables presented in this paper should be used by designers, architects, engineers or any other person in charge of purchasing and designing equipment and work stations for Chilean workers because this information is the most up-to-date and thorough dataset of Chilean anthropometrics.

3.5. Conclusion

Anthropometrics is a key input for sustainable and healthy product design. Many studies have focused on improving designs using anthropometrics, and up-to-date data are necessary to make those intentions a reality.

The survey included a total sample of 2946 workers, exceeding the minimum sample number estimated through ISO 15535 (2012). The anthropometric tables presented in this article should be used by designers and manufacturers as a data source to either produce or select products for Chilean adult workers. The male worker anthropometrics are significantly different from those of females, and the males presented larger values for all the dimensions except hip width. A significant difference between Chilean workers and their counterparts in the Netherlands, the US and South Korea was also found, and the results showed that Chileans were generally smaller than the first two populations and larger than the latter population.

The number of migrant workers in Chile dramatically increased during 2017; thus, further studies focused on workers should address ethnicity as a factor among the variables under study. The data in this paper are supplemented by detailed information available online free of charge through the anthropometric database published by DINED (www.dined.nl), a project that was originated in the 1980s by Molenbroek as part of a study at TU Delft University and was extended from a paper-based table into an information system for designers and researchers that is used by 50,000 users worldwide. Researchers and managers are advised to share anthropometric information with the international community to accommodate specific populations in a globalized world.

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CHAPTER 4| Educational level and its relationship with body height and popliteal height in Chilean male workers

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Carlos Viviani, Héctor Ignacio Castellucci, Pedro Arezes, Ángelo Bartsch, Sara Bragança, Johan F.M. Molenbroek, Marta Martínez and Verónica Aparici. Educational level and its relationship with body height and popliteal height in Chilean male workers. *Journal of Biosocial Science.* https://doi.org/10.1017/S0021932019000750

A secular trend in body height has been experienced in many nations and populations, hypothesized to be the result of better living conditions. Educational level has been shown to be closely associated with body height. This study examined the changes in body height and popliteal height in a group of adult Chilean male workers by age cohort and the relationship of these with educational level. The body heights and popliteal heights of 1404 male workers from the Valparaíso and Metropolitan regions of Chile were measured in 2016. The sample was grouped by level of education (primary, secondary, technical and university) and age (21–30, 31–40 and 41–50 years). Robust ANOVA and post-hoc analyses using a one-step modified M-estimation of location were conducted based on bootstrap resampling. Both body height and popliteal height increased from the older to the younger age cohort. The largest increase was from the 41–50 to the 21–30 group, with a 1.1% increase in body height and 1.7% increase in popliteal height. When educational level was introduced into the analysis there was a marked increase in both body height and popliteal height for each cohort, but only in primary- and secondary-educated workers. Despite showing an overall increase in body height and popliteal height, younger workers with the highest levels of education showed fewer differences between them than did older workers with less education. The differences were larger in the older than in the younger cohorts. Similarly, this trend was less clear in workers with higher levels of education (technical and university), probably because of a dilution effect caused by increased access to higher education by workers in the lower income quintiles.

Keywords: Secular trend; Lower Leg; Anthropometry.

4.1. Introduction

It has been hypothesized that body height (stature) is highly influenced by socioeconomic factors such as education and income level (Silventoinen, 2003; Gyenis & Joubert, 2004; Arcaleni, 2006; Baynouna et al., 2009; Bielecki et al., 2012; Som et al., 2014; Selita & Kovas, 2019). Body height has increased in many modern countries, particularly since the mid-20th century (Hermanussen et al., 2015). Better living conditions can increase a population's anthropometric dimensions, such as height (Fredriks et al., 2000; Silventoinen, 2003; Matton et al., 2007; Hanson et al., 2009; Schwekendiek & Jun, 2010; Bubaš et al., 2012; Tomkinson et al., 2017). On the other hand, scarcity and suffering experienced during childhood can decrease final adult height, highlighting inequalities within a given population (Cole, 2000, 2003; Hanson et al., 2009). Thus, height can be used as an indicator of well-being (Tanner, 1986). These positive and negative secular trends in height show that human growth usually is a complex phenomenon with both genetic and environmental causes, especially since growth is considered to be accumulated during the first 2 years of an individual`s life (Tanner, 1986, 1992; Cole, 2000, 2003).

Anthropometric dimensions change with time in adult populations. Although body height is a highly relevant and widely used anthropometric dimension, its measurements may not be accurate, mainly because of subject 'dependability': the variation due to physiological factors (Ulijaszek & Kerr, 1999; Sicotte et al., 2010). An example of dependability is the variation of height in the same subject at different times of the day, for, regardless of it's measured, height decreases throughout the day and can show a reduction of 1.4 cm (Tillmann & Clayton, 2001). Additionally, it is known that as people age they have a tendency to shrink (Sorkin et al., 1999). The osteo-degenerative changes in trunk dimensions associated with ageing, as reflected in trunk and body heights, have been called 'unreliable indicators of life-accumulated growth' (Stewart et al., 2015). Therefore, body height might be better complemented with the dimensions of other body segments, such as the lower leg (popliteal height), which express growth more accurately since they do not seem to be affected by age (Tanner et al., 1982; Bogin & Varela-Silva, 2010; Fernihough & McGovern, 2015). Popliteal height is defined as the vertical distance from the floor or footrest to the posterior surface of the knee (popliteal surface) (ISO, 2008). Leg dimensions have also been used to study relationships with other variables, such as cognitive function in mid-life (Stewart et al., 2015) and dementia (Prince et al., 2018), and to design school furniture for children (Castellucci et al., 2015a).

Education level has been shown to be highly associated with body height in several populations (Gyenis & Joubert, 2004; Arcaleni, 2006; Komlos & Lauderdale, 2007; Baynouna et al., 2009; Bielecki et al., 2012; Núñez & Pérez, 2015). This is thought to be due to people with higher levels of education tending to have better financial situations. In the case of Chile, since the 1990s, after democratization, several public policies have been put in place to improve the living conditions of the population. The CASEN surveys have been conducted in Chile with a consistent methodology every two or three years since 1990 to assess several aspects of welfare in Chilean society, including access to education. One major policy has been to extend access to higher education (both technical and university education). According to Espinoza and González (2007), who analysed higher education access data from 1990, 1993 and 2003 by household occupation (non-manual work, manual work, agriculture) using CIUO 88 following Erikson and Goldthorpe (1993), there has been a progressively increased access to higher education for students from homes where the primary income is manual work: from 12.2% in 1990, to 31.1% in 1993 and 33.3% in 2003.

In 2016, an anthropometric survey with an ergonomic purpose and design was conducted among Chilean male workers. In light of Chile's particular geographical characteristics, it was conducted in the two most populated regions. Subjects' age, height, popliteal height and highest educational attained level were obtained. The objective of the present study was to investigate differences in total body height and popliteal height in a cohort of male workers born in Chile between 1966 and 1996 in relation to their attained educational levels.

4.2. Methods

4.2.1. Study area and sample selection

Data were taken from a 2016 anthropometric survey of Chilean male workers performed for ergonomic purposes. The target population comprised adult male workers assigned to the second-largest workers' compensation company in Chile. The sample was selected from the two most populated regions of Chile – the Valparaíso and Metropolitan regions – mainly because of geographic constraints, since Chile is 4000 km long. The workers were employed in nine branches of economic activity (agriculture and fishing, mining, manufacturing, electricity, construction, commerce, transport and communications, financial services, and communal and personal services).

For each region, a stratified sampling plan using clustering was carried out by economic activity. For this investigation, each cluster corresponded to a group of 20 workers. To calculate the number of clusters in the sample significance was taken at $p<0.5$, which corresponds to the proportion of workers with anthropometric measures outside the usual ranges, as this proportion gives the maximum sample size or number of clusters to be selected from the population in each region. The estimated error was set at 0.04. To determine the number of clusters in the sample for each region, data on the average monthly number of workers assigned to the workers' compensation company and weighting by economic activity were used. Although the number of clusters per region was in accordance with the established sampling plan, for the Metropolitan Region it was decided to double the number of clusters in the sample due to the great number of workers in this region. For purposes of approximation, in all cases the number of clusters was rounded upward. Finally, data were collected on 1404 Chilean male workers aged between 21 and 50.

4.2.2. Data collection

Subjects were measured in the workers' compensation company facility when they attended their annual health check-up. The data collection process was approved by the Committee of Ethics at the Chilean Construction Chamber (Camara Chilena de la Construcción). Written consent was obtained from the workers before starting the measurement procedures. Direct measurements from each subject were made of 29 anthropometric dimensions, including body height and popliteal height. Popliteal height was measured with the subject sitting with 90° knee flexion and defined as the 'vertical distance from the floor or footrest to the posterior surface of the knee' (popliteal surface).

Great care was taken to use correct measurement techniques to obtain accurate anthropometric measurements, according to ISO 7250-1 standards (ISO, 2008). All subjects were measured from the right side while lightly clothed and without shoes. The measurement process was carried out by six physiotherapists divided into two teams. Before starting the survey, they went through training sessions (theory and practice) and spent a considerable amount of time practising the measurements to achieve high consistency between measurers. At the end of the training sessions, a pilot study was developed with a sample of 25 volunteers who were measured twice by the two teams, and both inter- and intra-measurer reliability were assessed using the Intraclass Correlation Coefficient (ICC) two-way mixed and absolute agreement models. Correlations were interpreted according to the ranges suggested by Portney and Watkins (2008): ICC ≥0.50 was interpreted as moderate and ICC ≥0.75 was interpreted as strong. The results showed that the measures had strong inter- and intra-reliability values for body height and popliteal height.

Subjects' age was confirmed by their personal identification documents and classified in three cohorts: 21–30 (born 1986–1995), 31–40 (born 1976–1985) and 41–50 (born 1966–1975).

The subjects were not classified by ethnicity, as a previous study by Chilegenomico (2015), the first and only genetic study conducted in Chile, found no ethnic differences among 3200 Chileans from eight cities across the north, centre and south of the country. Genetically, Chileans are 51% European, 44% Amerindian and 3% African. The sample only included workers born in Chile. Data collection, in 2016, occurred before Chile received a large number of migrants from Haiti, who are mainly of African ethnicity (Rojas & Silva, 2016). According to an El Mercurio Newspaper article dated 10th April 2018, during 2017 a migration peak occurred, specifically from Haiti, when 100,000 Haitian migrants entered the country with a tourist visa; however, 98% of them changed their visa status to a work visa or temporary visa.

The participants were also asked about their level of education, and this was classified into ‘primary’, ‘secondary’, ‘technical’ or ‘university’ education. A similar approach has been used in other studies to establish a socioeconomic proxy for educational level (Komlos & Lauderdale, 2007). Details of the final sample composition are given in Table 4.1.

Table 4.1. Sample of Chilean male workers by age cohort and educational level

Age cohort	Primary	Secondary	Technical	University	Total (%)
21–30	23	260	97	117	497 (35.4)
31–40	24	277	80	144	525 (37.4)
41–50	41	225	58	58	382 (27.2)
Total (%)	88 (6.3)	762 (54.3)	235 (16.7)	319 (22.7)	1404

4.2.3. Statistical analysis

The statistical software R was used to perform descriptive statistics and hypothesis testing. Means and standard deviations for the age and education variables (and their established levels) were computed. After a homoscedasticity rejection with the Bartlett test ($p>0.05$), robust ANOVAs and post-hoc analyses using one-step-modified M-estimation of location were conducted based on bootstrap resampling ($n=5000$) (Mair & Wilcox, 2019). Absolute and relative differences between the samples were calculated, with changes expressed in percentages and in absolute values (in mm).

4.3. Results

Table 4.2 shows the average (±SD) age, body height and popliteal height of the sample workers by educational level. Those in the 21–30 cohort were taller than those in the 31–40 cohort, who in turn were taller than those in the 41–50 cohort. However, when examined by each educational level, there was a height difference between cohorts only in those with primary and secondary education. In other words, the body height of workers with only primary and secondary education decreased by age group (older workers were shorter) but increased from primary to secondary education level; that is, workers with secondary education were taller than those with only primary education. This did not hold, however, for technical- and university-educated workers.

Table 4.2. Body height and popliteal height of Chilean male workers by age cohort and education level

	Age cohort	Primary Mean±SD	Secondary Mean±SD	Technical Mean±SD	University Mean±SD	Total Mean±SD
Body height (cm)	21–30	170.6±4.5	171.9±5.6	171.8±5.5	173.6±6.7	172.2±5.9
	31–40	169.7±5.2	170.9±6.3	172.4±7.1	174.2±6.6	172.0±6.6
	41–50	167.7±6.3	169.7±5.9	172.2±6.3	173.2±5.6	170.4±6.2
	Total	169.0±5.7	170.8±6.0	172.1±6.3	173.8±6.5	171.6±6.3
Popliteal height (mm)	21–30	441.2±17.0	442.0±20.8	444.4±19.1	446.7±23.0	443.5±20.9
	31–40	433.7±21.8	438.6±22.3	444.0±25.4	445.8±23.1	441.2±23.2
	41–50	426.6±21.6	435.7±21.7	439.8±19.5	441.1±19.9	436.2±21.4
	Total	432.4±21.2	438.9±21.7	443.1±21.5	445.3±22.6	440.7±22.1

Table 4.2 shows that the average body height of 21–30 technical-educated workers was less than that of both 31–40 and 41–50 technical-educated workers. Also, the average body height of 21–30 university-educated workers was less than that of 31–40 workers in the same category, but greater than in those aged 41–50. Conversely, popliteal height showed a stable increase in all categories independent of educational level.

Table 4.3 shows the absolute and relative body height and popliteal height differences between sample age cohorts by educational level. An overall increasing trend in both body height and popliteal height can be seen. This trend was more explicit and statistically significant when comparing body height and popliteal height for 21–30 and 41–50 workers. When including educational level, the differences were statistically significant only when comparing the heights of 21–30 and 41–50 workers with secondary education, and the popliteal height of 21–30 and 41–50 workers with primary and secondary education. Despite not being always statically significant, there was a continuous increase in the dimensions of the younger (21–30) and older workers (41–50) with primary and secondary education. This effect weakened when comparing younger workers with technical and university education, even reversing in some cases.

Table 4.3. Differences in mean body height (cm) and mean popliteal height (mm) of Chilean male workers by age cohort and educational level

	Primary		Secondary		Technical		University		Total	
	cm	%	cm	%	cm	%	cm	%	cm	%
Body height (cm)										
21–30 vs 41–50	2.93	1.7	2.23***	1.3	–0.44	–0.3	0.39	0.2	1.82***	1.1
21–30 vs 31–40	0.90	0.5	0.99	0.6	–0.60	–0.3	–0.58	–0.3	0.24	0.1
31–40 vs 41–50	2.03	1.2	1.24	0.7	0.16	0.1	0.98	0.6	1.57*	0.9
Popliteal height (mm)	mm	%	mm	%	mm	%	mm	%	mm	%
21–30 vs 41–50	14.58***	3.4	6.28***	1.4	4.67	1.1	5.53	1.3	7.36***	1.7
21–30 vs 31–40	7.51	1.7	3.38	0.8	0.46	0.1	0.90	0.2	2.37	0.5
31–40 vs 41–50	7.07	1.7	2.91	0.7	4.22	1.0	4.63	1.1	4.99***	1.1

*p<0.1; **p<0.05; ***p<0.01.

Table 4.4 shows comparisons of body height and popliteal height by age cohort and educational level. The analysis of total increase in heights by educational level showed statistically significant differences. The largest differences in total average body height were in workers who attended university versus those with only primary education (2.8%), followed by workers with technical education versus those with primary education only (1.9%), and workers with university education versus secondary education (1.7%). Popliteal height followed the same trends as in the previously mentioned categories, with differences of 3.0%, 2.5% and 1.4%, respectively.

Table 4.4. Differences in mean body height (cm) and mean popliteal height (mm) of Chilean workers by age cohort and educational level

	Univ vs TE		Univ vs SE		Univ vs PE		TE vs SE		TE vs PE		SE vs PE	
	cm	%	cm	%	cm	%	cm	%	cm	%	cm	%
Body height (cm)												
21–30	1.79	1.0	1.70	1.0	2.96	1.7	−0.08	0.0	1.17	0.7	1.26	0.7
31–40	1.78	1.0	3.28***	1.9	4.44***	2.6	1.50	0.9	2.66	1.6	1.17	0.7
41–50	0.96	0.6	3.54***	2.1	5.49***	3.3	2.59**	1.5	4.54***	2.7	1.95	1.2
Total	1.60***	0.9	2.90***	1.7	4.78***	2.8	1.30***	0.8	3.18***	1.9	1.88**	1.1
Popliteal Height (mm)	mm	%	mm	%	mm	%	mm	%	mm	%	mm	%
21–30	2.23	0.5	4.67	1.1	5.45	1.2	2.44	0.5	3.22	0.7	0.78	0.2
31–40	1.80	0.4	7.15*	1.6	12.06*	2.8	5.35	1.2	10.27	2.4	4.91	1.1
41–50	1.38	0.3	5.42**	1.2	14.50***	3.4	4.04*	0.9	13.12***	3.1	9.08**	2.1
Total	2.18***	0.5	6.29***	1.4	12.90***	3.0	4.11***	0.9	10.72**	2.5	6.61**	1.5

*p<0.1; **p<0.05; ***p<0.01. TE, technical education; Univ, university education; SE, secondary education; PE, primary education.

Table 4.4 also shows that the younger and more highly educated the workers, the fewer significant differences there were in body height and popliteal height, similar to what was observed in Table 4.3. For example, one of the largest differences in the percentage of body height (3.3%) and popliteal height (3.4%) was observed in the 41–50 cohort, when comparing university-educated workers with those with only primary education. On the other hand, Table 4.4 shows that there were no statistically significant differences within the 21–30 cohort by educational level for either body height or popliteal height. There were fewer significant differences in the 31–40 cohort when comparing workers with technical education versus primary and secondary-educated workers or secondary versus primary-educated workers. As for university- versus technical-educated workers, there were no significant differences in any of the age cohorts.

When comparing the workers by age groups and educational level, the differences were significant for body height for the 21–30 versus 41–50 workers with secondary education. The same held true for popliteal height for 21–30 versus 41–50 workers with both primary and secondary education. The differences, however, were progressively smaller when comparing younger workers with higher education. For example, body height showed differences of 2.93 cm and 2.23 cm ($p<0.01$) between 41–50 and 21–30 workers with primary and secondary education, respectively, while the same comparison between 41–50 and 31–40 workers yielded 2.03 cm and 1.24 cm, respectively. The same comparison of body height showed much greater discrete differences, and even negative results, when making comparisons between younger educated workers. Comparing the body heights of workers aged 31–40 and 21–30, the differences were 0.90 cm and 0.99 cm in those with primary and secondary education, respectively, and −0.6 cm and −0.58 cm for those with technical and university education levels, respectively. Popliteal height behaved similarly, but the differences appeared more clearly in the same comparisons, where 41–50 versus 21–30 workers with primary education showed differences of 14.58 cm ($p<0.01$) and 6.28 cm ($p<0.01$) in workers in the same age ranges with secondary education. In primary and secondary-educated workers, popliteal height differences between workers aged 41–50 and 31–40 were 7.07 cm and 2.91 cm, respectively, and the differences in the 31–40 versus 21–30 cohort were 7.51 cm and 3.38 cm, respectively.

4.4. Discussion

4.4.1. Effect of improvements in living conditions in Chile

The socioeconomic background of these Chilean workers seems to have influenced the observed secular trend in body and popliteal heights, particularly when comparing workers with primary and secondary education. Both body height and popliteal height increased from the older to the younger age cohort, but when considering educational level, in primary and secondary educated workers, a significant increase in both variables was observed for each cohort. Despite showing an overall increase in body height and popliteal height, younger workers with the highest levels of education showed fewer differences between them than did older workers with less education

People who experience less-favourable situations frequently achieve a greater increase in their quality of life, even with only small improvements (Hoddinott & Wiesmann, 2010), which could explain the fact that the secular trend was more evident with each successive cohort in workers with primary and secondary education, but not in more highly educated workers. Generally, disadvantaged people tend to have lower levels of education (Singh-Manoux et al., 2010; Huang et al., 2015), which can serve as a proxy for socioeconomic status, explaining why the secular trend was evident only in workers with primary and secondary education. Chilean children and adolescents have shown a positive secular trend in growth over the last 30 years (Valenzuela & Avendaño, 1979; Argote & Portales, 1992; Gutiérrez & Apud, 1992; Burrows et al., 2010; Castellucci et al., 2015b; Núñez &

Pérez, 2015); thus, it is possible that these increases contributed to the overall (total) average body height increase. Since the 1960s, Chile has experienced almost constant improvements in its Gross Domestic Product (GDP) per capita (World Bank, 2018) and a constant decrease in child mortality, decreasing from 120 deaths per 1000 births/year in 1960 to 7.4 deaths per 1000 births/year in 2010 (Deis-Minsal, 2014) – both being indicators of the country's improved living conditions. According to the Food and Agriculture Organization of the United Nations 1990–2016 (FAOSTAT, 2018), Chile has experienced a decrease in undernourishment, with a transition from health problems related to child undernutrition towards the chronic non-transmissible illnesses associated with obesity, similar to what has been happening in developed countries and economies (Muzzo et al., 2004; Kagawa et al., 2016).

The better living conditions experienced in Chile over recent decades have no doubt positively influenced the secular growth of the workers in this study, since they have increased well-being, health and overall growth (Tanner, 1992; Bogin, 2001; Cole, 2003).

4.4.2. Effect of opening up of higher education in Chile

The second and most likely explanation for the observed changes in height and popliteal height of the studied cohorts, is the opening of higher education to students of lower socioeconomic status in Chile over recent decades. Access to higher education in Chile has increased since 1990 (Espinoza Díaz & González Fiegehen, 2007; Rolando et al., 2010; Arzola, 2011). An indicator used by the Chilean Government to assess higher education participation is the Net Assistance Rate, defined as the total population aged 18–24 years that entered higher education divided by the total population aged 18–24 years old (Ministerio de Desarollo Social, 2016). When access to higher education is analysed by income quintile, historically since 1990 the fifth (richest) quintile has continued to have greater access to higher education, moving from a 33.2% Net Assistance Rate in 1990 to one of 59.0% in 2011 (MIDEPLAN, 2013), showing an increase of 77.7%. In 1990 only 4% of the population between the ages of 18 and 24 years from the first (poorest) income quintile accessed a higher education institution, and this increased to 22.1% by 2011, showing an increase of 452.5%. Therefore, the first and second income quintiles (two lowest) have experienced the most dramatic increase in participation in higher education over the period. Also, considering the data from Rolando et al. (2010) and Arzola (2011), Figure 1 shows that in 1990 only 5.3% of students between the ages of 18 and 24 years in the first (poorest) quintile were enrolled in higher education, while in 2011 this increased to 12.8%. Conversely, in 1990, 39.2% belonged to the fifth quintile, falling to 26.8% in 2011, clearly showing increased access to higher education for the lower economic segments of the population.

It is worth mentioning that, in accordance with the traditional Chilean school year, workers with higher education (technical and university) most likely attended higher education between the following intervals: the 21–30 cohort attended higher education between 2004 and 2013, the 31–40 cohort between 1994 and 2003, and the 41–50 cohort between 1984 and 1993. The increase in the participation of the lower income quintiles with time for the selected years is illustrated in Figure 4.1.

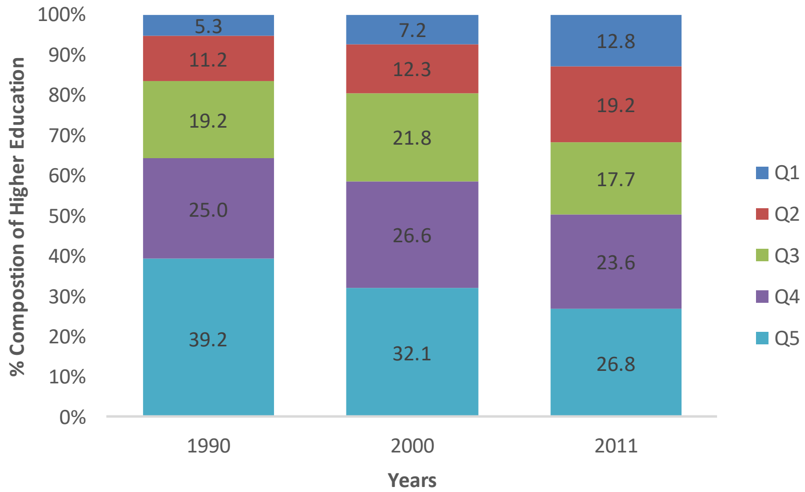

Figure 4.1. Percentage of students with higher education by income quintile (Q1–Q5, where QI is poorest and Q5 is richest) using data from Arzola (2011) and Rolando *et al.* (2010).

This increased participation may explain the lack of significant differences observed in the more educated and younger workers of the current study, where the 21–30 workers with higher education showed a much more diluted distribution of height and popliteal height, which is likely to be associated with greater access to higher education for lower income quintiles. Public policies, such as higher education scholarships and state-endorsed student loans, have made a significant contribution since they are intended to provide greater access to higher education for students of lower socioeconomic levels (OECD, 2004, 2009; Benavente & Alvarez, 2012; MIDEPLAN, 2013). It is estimated that between 1991 and 2000, public spending in Chile on higher education increase by 74% in real terms (OECD, 2004). Also, since 1990, regulatory changes made possible a significant increase in the number of private higher education institutions, whose student enrolment has increased 10 times, many of them coming from lower socioeconomic backgrounds (Ministerio de Desarollo Social, 2016). According to the 2015 CASEN survey, 49.8% of the first quintile and 49.3% of the second quintile students between 18 and 24 years old had some type of direct scholarship that helped to pay for higher education tuition (Ministerio de Desarollo Social, 2016). The CASEN 2015 survey also showed that 44.9% and 39.6% students between 18 and 24 years old from the first and second quintiles, respectively, had student loan credits endorsed by the Chilean state or direct student loans from the Chilean state. The combination of state-endorsed loans and scholarships and access to more private universities is a very likely explanation for the increase in higher education access, especially for the lower income quintiles (OECD, 2009).

When analysing the differences in average height and popliteal height found in each cohort, popliteal height indicates more accurately than body height the social or environmental factors experienced by subjects, especially during early childhood or adolescence, as has been suggested by previous research (Vázquez-Vásquez et al., 2013). Further studies could perform an in-depth analysis of these anthropometric variables to complement height, to obtain an authentic anthropometric variable more sensitive to environmental/societal factors

Similar findings in other populations

The differences in body height found in the current study are very similar magnitude to those found by other studies. For example, Huang et al. (2015) found a positive relationship between height and educational level among Dutch male conscripts, with differences varying monotonically over a 5.1 cm range between the conscripts with the highest and lowest education, whereas in the current study the difference between workers with university education and primary education was 4.78 cm ($p<0.01$). The study by Meyer and Selmer (1999) in Norwegian males and females born in 1926 and 1941 found more moderate differences in height than the current study, with a difference of 3.3 cm in males with the highest and lowest level of education. As in the current study, both of these studies found that the younger the birth cohort, the less notable the difference in height. This may be attributed to constant improvements in the welfare state and social policies impacting the subjects' childhood during the period under study. Smaller differences in the height of younger cohorts have also been observed in male Polish conscripts born between 1957 and 1967 (Bielicki et al., 1992) and in Swedish men (Magnusson et al., 2006), even after controlling for other socioeconomic variables. These findings could point to a likely explanation of why in the current study the differences in the younger cohorts were less pronounced, especially in the case of Chile, with a mixture of improvements in living conditions and the opening up of higher education.

The current study suggests that body height changes might be associated with the opening up of higher education to lower income quintiles. According to Komlos and Lauderdale (2007), when there is greater social mobility, there is less of an association between adult income or education and body height, even when comparing data across generations. This might well be an explanation of the results of this study. Another study (Komlos & Baur, 2004) found that stature increased in US adults with each higher educational level reached, contrary to the findings of this study, which mainly reflects the nature of the US higher education system, where access requires a certain socioeconomic status or debt capacity, since it is one of the most expensive in the world. In fact, it would be interesting to analyse this trend with a larger sample a decade from now, as recently the Chilean government has established a programme to offer free higher education to all students in the lowest 60% income levels.

4.4.3. The Chilean school system reflects inequalities more clearly through body height and popliteal height

Contrary to body height in tertiary education, schools are one area in Chile where body height and other anthropometric dimensions such as popliteal height are more closely related to social inequalities. There are marked anthropometric differences among low-, middle- and upper-income school children, which are reflected in the three types of schools (public, endorsed, and private) (Castellucci et al., 2015b), mainly because of a clear quality gap among these educational levels, which makes for distinct social and anthropometric differentiation, where taller children attend private schools and shorter children attend public schools (Castellucci et al., 2015b, 2016).

4.4.4. Study strengths and limitations

The study has its limitations. First, neither the height nor the educational level of the subjects' parents was documented, which could have more precisely defined their socioeconomic levels. Second, the sample size could have been larger and included more regions of Chile. Broadly speaking, more detailed anthropometric surveys require more resources and time; thus, in developing countries such as Chile, it presents an additional challenge, especially considering Chile's particular geographical characteristics – its length of 4000 km, which is equal to nearly the entire expanse of Europe – where the costs of implementing a nationwide anthropometric survey would be very high. Despite that, the study sample was representative of the two most populated regions of Chile, Valparaíso and Metropolitana, where more than 50% of the population lives. Further studies should use a larger sample and account for parental height or education before generalizing to the entire Chilean male working population.

The strengths of this study were the directly measured anthropometric dimensions. It is well known that the bias of self-reported height and weight can affect the overall perception of a population's health (Shiely et al., 2013). Also, a standardized procedure was followed throughout data collection and, furthermore, the people performing the measurements were tested according to their intra- and inter-reliability, which additionally reduced the possibility for error. It would be interesting to account for any relationships between body height and popliteal height with educational level, especially 10 years from now, since a recently approved law stipulates that higher education should be free for the first six income deciles.

4.5. Conclusions

A clear secular increase in body height and popliteal height was observed among Chilean male workers across all age cohorts. The overall secular increase can be attributed to improvement of living conditions in Chilean society, especially in younger workers, who have experienced the more recent benefits of improvements in Chilean society. However, when analysing the sample by educational level and age, the trends were only well-defined for workers with primary and secondary education in all age groups. The trend was increasingly diluted when looking at each successive younger and more highly educated group of workers. This finding probably has to do with the opening up of access to higher education since 1990, contributing to the dilution effect in height and popliteal height in the more educated and younger workers. The findings of this study could indicate that in the case of Chile, educational level may no longer be associated with height or socioeconomic situation in adults with technical or university education, and thus other variables should be included to establish the socioeconomic background of subjects, not only educational level.

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Conflict of Interests. The authors have no conflicts of interest to declare.

Ethical Approval. The data collection process was approved by the Committee of Ethics at the Chilean Construction Chamber (Camara Chilena de la Construcción, 2015). The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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CHAPTER 5| Secular changes in the anthropometrics of Chilean workers and its implicance in design

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Castellucci, HI, Viviani, CA, Molenbroek, JFM, Arezes, PM, Martínez, M, Aparici, V, Bragança, S. Secular changes in the anthropometrics of Chilean workers and its implicance in design. *WORK: A Journal of Prevention, Assessment & Rehabilitation*

BACKGROUND: Anthropometrics is very important when ensuring a physical match between end users and product or workstations.

OBJECTIVE: The purpose of this study are twofold, to provide anthropometric data for the design of products and to examine the secular changes in the adult Chilean workers in a period of more than 20 years.

METHODS: The study compares eighteen anthropometric measurements from two samples gathered in 1995 and 2016.

RESULTS: The secular trend observed for Stature is characterized by an increase average of 20 mm and 10.5 mm per decade for females and males, respectively. There is a positive secular trend for both genders, which is observed for most of the selected body measurements. The most pronounced increases were on Weight, Shoulder breadth, Popliteal height; Buttock-popliteal length and Hip width.

CONCLUSIONS: Those segmental dimensions that experienced a positive secular trend, together with Weight and Stature, are highly correlated with seating design, addressing the need to review products targeting Chilean adult workers, such as public transport seats, office furniture or industrial workplaces.

KEYWORDS: Design; Anthropometry; Chile; Secular trends in anthropometry

5.1. Introduction

Anthropometry is the branch of the human sciences that is concerned with measurements of size, weight and proportions of the human body, with the aim of achieving comfort, optimal fit and usability (1).

In an ideal design process, anthropometry is used to decide the most relevant dimensions of products and workspaces, for example Popliteal height (height taken from the floor to the back of the knee) is often used to determine the height of chairs (2). All products for the final user, as well as products for work systems, including clothing, personal protection elements, office stations, vehicles and production lines need to be adjusted to the anthropometric characteristics of the population. This will help to maximize usability and productivity and to minimize the negative effects on end users (3).

There is a wide number of studies that have applied anthropometrics in order to achieve optimal design and fitting standards (4–16) Anthropometric data (or sometimes called anthropometric tables) are a technical reference for the design of products, spaces and work systems. This is especially important because through the digital modeling of anthropometric data with biomechanical criteria, it is possible to simulate the interaction between the users and the system. This allows accommodating the usual human variability, thus helping to prevent injuries and improve productivity (1). Incorrect products' and workplaces' dimensions coupled with inadequate anthropometric dimensions lead to discomfort, pain and injuries in the neck, shoulders, arms, wrist and back (2,17,18).

The first anthropometric data base of Chilean workers developed by (19) have been the only data referring to body dimensions until very recently. The use of these data (or tables) could make designs inadequate, mainly if one considers that the data can be outdated, in particular due to the existence of a well-known secular trend. The secular trend is the growth observed in some populations over long periods of time. It has been defined as an increase in average stature between people of the same age along successive generations (20). Whether this increase is evenly distributed throughout the body or only in certain segments is not yet fully known (21). This positive secular trend has been observed in different countries, with an average growth in Stature between 0.7 cm and 4.0 cm per decade (22,23). A positive secular growth has been experienced in many countries (3,20,24–28) and on specific adult populations, such as Dutch college students (29), US adult civilians and military personnel (30) and Australian air force personnel (25), among others. Furthermore, this positive secular trend can stop after a period of continuous growing, such was the case for the Dutch population, which stopped growing taller after a period of almost 150 years. The cause for this is still unclear (31). It is generally assumed that this secular trend is caused by changes in environmental conditions, in particular due to the elimination of factors that would have blocked the full expression of biological (genetic) potential, such as infectious diseases, inadequate nutrition, poverty and suffering (32). A positive secular trend is also assumed to reflect changes in living standards and dietary habits (33).

The analysis of the positive secular trend is a very important factor that was considered in the current study since the anthropometric data from Chile correspond to a data collection done in 1995, which may indicate that the data may be outdated. To reinforce the aforementioned and, based on the anthropometric measures of 3,078 Chilean school children evaluated by the authors (34), it was shown that there was an increase in mean Stature, Popliteal height, Hip width and Buttock-popliteal length, in both boys and girls. Thus, it was presumed that a positive secular trend would be present in the Chilean adult population as well.

The use of incorrect anthropometric dimensions and the failure to consider the changes resulting from secular trend threatens the sustainability of products and spaces over time, since in the face of possible problems, they will have to be modified, with the costs involved once they have been manufactured (35).

The aim of the current study is to present anthropometric data for the design of products as well as to examine the design implications of the secular changes observed in a group of anthropometric variables for Chilean workers during the period between 1995 and 2016.

5.2. Methods

5.2.1 Samples

For this study two samples were selected for comparison, one from 1995 and the other one from 2016. Both studies followed the same measurement protocol (36,37) and used the same anthropometer (Harpender, Holtain) to collect the data.

No information was available regarding the weighting scales used to collect Weight data in 1995. Despite the fact that more dimensions were gathered in both samples, after a previous detailed analysis only 18 anthropometric measures (common for both studies) were considered for comparison in this study (Table 5.1 and Figure 5.1). Data extracted from both samples were collected for ergonomic purposes, specifically for the design and evaluation of workplaces.

Table 5.1. Anthropometric measurements considered in the studies of 1995 and 2016

Anthropometric measurements	Definition
1. Weight (Kgs)	total mass (weight) of the body
2. Stature	vertical distance between the floor and the top of the head. and measured with the subject erect and looking straight ahead (Frankfort plane).
3. Eye height standing	vertical distance from the floor to the inner canthus (corner) of the eye (head in Frankfurt plane).
4. Shoulder height standing	vertical distance from the floor to the acromion.
5. Elbow height standing	taken with a 90° angle elbow flexion. as the vertical distance from the bottom of the tip of the elbow (olecranon) to the floor.
6. Knuckle height	vertical distance from the floor to metacarpal III (i.e. the knuckle of the middle finger).
7. Sitting height	vertical distance between subject's seated surface to the top of the head. and measured with the subject erect and looking straight ahead (Frankfort plane).
8. Eye height sitting	vertical distance between the sitting surface to the inner canthus (corner) of the eye (head in Frankfurt plane).
9. Shoulder height sitting	vertical distance from subject's seated surface to the acromion.
10. Elbow height sitting	taken with a 90° angle elbow flexion. as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
11. Abdominal depth	maximum horizontal distance from the vertical reference plane to the front of the abdomen in the standard sitting position.
12. Thigh clearance	vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
13. Buttock-Popliteal Length	horizontal distance from the popliteal surface to the rearmost point of the buttock.
14. Buttock-Knee Length	horizontal distance from the foremost point of the knee-cap to the rearmost point of the buttock.
15. Popliteal height	vertical distance from the floor or footrest to the posterior surface of the knee (popliteal surface).
16. Shoulder breadth	distance across the maximum lateral protrusions of the right and left deltoid muscles.
17. Elbow breadth	maximum horizontal breadth across the elbows.
18. Hip width	horizontal distance measured in the widest point of the hip in the sitting position.

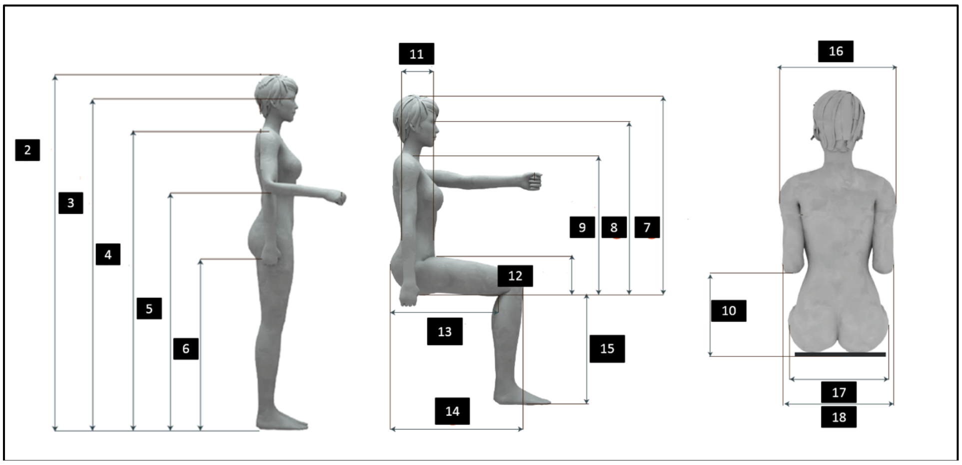

Figure 5.1. Anthropometric measurements considered for comparison.

5.2.1.1. Sample from 1995

Although the publication year of the anthropometric tables made by Apud and Gutierrez was 1997, the data was actually collected in 1995 (Gutiérrez personal communication). The sample from 1995 included 3,765 Chilean workers from the Concepción Region (1,735 females and 2,030 males), and the collection of 20 and 22 anthropometrics measures for females and males, respectively. The samples consisted of workers from three economic activity sectors (Agriculture and fishing; Manufacturing; and Communal and personal services).

The measurement process was carried out by two people, which were able to switch between roles, i.e. from measurer to recorder and vice-versa. Before starting to collect data, the two measurers/recorders underwent a training session, where they were provided with the definitions of each body dimension and, each measurement procedure, was demonstrated by an experienced anthropometry specialist. In the laboratory, the execution of the measurements was verified and corrected and, subsequently, field execution was monitored. Finally, quality data was assessed by analyzing and deleting all data without the range of ±3 standard deviations regarding the average (considered outliers).

5.2.1.2. Sample from 2016

Data from the sample of 2016 was collected by the authors of this article as a part of a larger research project, which include the collection of a total of 32 anthropometrics measures. Data were collected on 2,946 workers (600 female and 2,346 male) from the two most populated regions of Chile (Valparaíso and Metropolitana) distributed by 9 economic activity sectors (Agriculture and fishing; Mining; Manufacturing; Electricity; Construction; Commerce; Transport and communications; Financial services; and Communal and personal services).

The measurement process was carried out by a team of six physiotherapists, divided in two teams. Before starting the survey, the measurement teams underwent a one-week training session, including a theoretical approach to anthropometrics, as well as practical instructions lectures. They spent a considerable amount of time practicing the measurements in order to achieve high consistency between measurers. At the end of the training session, a pilot study was developed with a sample of 25 volunteers, which was measured twice by the two teams and both inter- and intra-measurer reliability were assessed using the Intraclass Correlation Coefficient (ICC) model's "two-way mixed" and "absolute agreement" types. Correlations were interpreted according to the ranges suggested by Portney and Watkins (38), namely an ICC≥0.50 was interpreted as being moderate and an ICC≥0.75 was interpreted as being strong. The results from Table 5.2 show that measurers have a strong value of inter- and intra-reliability.

Finally, quality data process was done through different steps, namely: observation of mean, minimum, and maximum values, calculation of the different measurements, observation of scatter plot graphics (Stature and Weight with the other variables) and percentiles' profile.

Table 5.2. Intra and Inter-measurer reliability (ICC values)

Anthropometric dimension	**Measurer 1**	**Measurer 2**	**Inter-measurers**
Weight	0.999	0.997	0.990
Stature	0.999	0.996	0.984
Eye height standing	0.788	0.898	0.782
Shoulder height standing	0.941	0.912	0.930
Elbow height standing	0.901	0.703	0.793
Knuckle height	0.980	0.983	0.970
Sitting height	0.951	0.936	0.937
Eye height sitting	0.788	0.898	0.782
Shoulder height sitting	0.941	0.912	0.930
Elbow height sitting	0.901	0.703	0.793
Abdominal depth	0.953	0.949	0.942
Thigh clearance	0.864	0.866	0.879
Buttock-Popliteal Length	0.910	0.789	0.878
Buttock-Knee Length	0.977	0.895	0.956
Popliteal height	0.940	0.967	0.929
Shoulder breadth	0.974	0.982	0.975
Elbow breadth	0.952	0.937	0.948
Hip width	0.781	0.761	0.784

5.2.2. Statistical analysis

An independent t-test (with a 95% confidence interval) was performed to examine the differences in the considered measurements between the samples of 1995 and 2016. Although the normality of the 1995 sample was not calculated, due the impossibility to access to the full data set, t-tests can be considered fairly robust for validity against non-normality (39). Absolute and relative differences between the two samples were calculated, with positive changes (+) indicating secular increases in mean values, and negative changes (–) indicating secular declines in mean values. Finally, to express the observed change per decade, the absolute difference was divided by 2.1, since the difference between the two studies was 21 years or 2.1 decades.

5.3. Results and discussion

As shown in Table 5.3 and Table 5.4, out of the 18 anthropometric dimensions compared, 13 presented a positive secular growth for both genders. The body dimensions with a greater % increase (for both Female and Male) along this 20-year period were:

- Weight (F: 10.3% M: 17.5%),
- Shoulder breadth (F: 11% M: 14.7%);
- Popliteal height (F: 13.7% M: 8.8%);
- Buttock-popliteal length (F: 9.1% M: 7.9%);
- Hip width (F: 7.3% M: 5.4%).

It is usual to see in anthropometrics comparisons among other populations mainly to see relevant differences or similarities that could traduce in sharing some designs or creating new ones (40–43). The secular increase shown by Chilean workers was expected and is somehow comparable to other populations, such as the Swedish and Dutch adult populations. According to relatively recent research (3), the Swedish adult population experienced a significant increase on Popliteal height (F: 11.8% M: 13%), Hip breadth (F: 13,4% M: 8,3%) Shoulder breadth (F: 8.9% M: 2.5%) and Weight (F: 9.8% M: n/a); which was more or less similar to the one experienced by the Chilean adult population. The Dutch adult population also showed and increase on similar dimensions, however, it was more discrete than the one found with Chilean adults, with the most relevant increase occurring for body dimensions such as Hip width (F: 7% M: 7%), Thigh clearance (F: 5% M: 5%), Elbow height seated (F: 10% M: 10%), Eye height seated (F: 1.5% M: 1.5%) and Popliteal height (F: 0.5% M: 1%) (29). This different scenario for the Dutch population might be explained by the stoppage in growth experienced in this country (44) and the fact that this population has probably achieved their maximal genetic potential, mainly due to better living conditions (Tanner, 1992). Other dimensions that showed an increase on Chilean workers for both genders were Knuckle height (F: 4.5% M: 2.3%), Buttock-knee length (F: 2.3% M: 2.7%), Shoulder height standing (F: 2,8% M: 1,7%), Sitting height (F: 1.8% M: 1.7%), Eye height standing (F: 1.9% M: 1.1%) and Thigh clearance (F: 1.7% M: 18.1%).

Regarding the design implications of these changes, the increase observed in the Chilean adult working population points out that there is a need to update designs, especially those associated with the seated posture. According to Molenbroek et al.

(29), increments on the dimensions described previously would definitively have an impact on chair and sitting design in general. For example, Shoulder breadth, Shoulder height sitting, Buttock-popliteal distance, and Hip width; are directly used as fitting criteria for backrest width, backrest height, seat depth and seat width. Another very relevant measure to the seated posture and design is Popliteal height, used to establish seat height (45). According to Molenbroek et al. (29), the mismatch could be greater on products that are used for extended periods of time, such as airplanes, buses and train seats, where secular changes may not be accounted for due to a lack of update on the changes of their respective designs. For example, besides regular sitting criteria, buttock-knee distance is used to design seat pitch on tandem seats (distance between the front and back seats) and is critical for the determination of leg room (29). According to other authors, passengers' comfort in aircraft seat design (46) is related to seat widths and depths and have a significant impact on the users' perceptions of comfort (13). The increase of the anthropometric dimensions previously mentioned also have an impact on office furniture design, especially non-adjustable ones, since the same variables that experienced an increase may affect the chair/desk match. For example, the case of Chilean males shows an increase of 18,1% on thigh clearance, therefore the under de table space on fixed working stations, desks and production lines could be unfitted specially for Chilean males. Thus, public transport and seated design standards for Chilean adult population should be reviewed with the data presented on this paper in order to analyze possible mismatches. Without a doubt that many other designs should be reviewed, especially those using the dimensions presented on this paper such as tools (47), industrial workstations (48) and personal protective equipment (14).

Table 5.3. Anthropometric Female data from the 2016 and 1995 studies

Anthropometric Dimension (mm)	2016		1995		Difference	
	Mean	SD	Mean	SD	Absolute value	%
Weight (Kgs)	66.87	12.00	60.7	10.1	6.2**	10.3
Stature	1593.20	60.60	1549.0	62.0	44.2**	2.9
Eye height standing	1488.31	60.39	1461.0	57.9	27.3**	1.9
Shoulder height standing	1316.14	55.78	1280.0	50.6	36.1**	2.8
Elbow height standing	977.31	46.34	966.0	39.1	11.3**	1.2
Knuckle height	711.37	34.79	681.0	36.6	30.4**	4.5
Sitting height	859.86	32.38	845.0	33.5	14.9**	1.8
Eye height sitting	754.97	31.99	758.0	35.6	-3.0	-0.4
Shoulder height sitting	582.80	26.53	577.0	31.9	5.8**	1.0
Elbow height sitting	243.97	24.78	266.0	31.3	-22.0**	-8.3
Abdominal depth	238.18	49.41	251.0	39.7	-12.8**	-5.1
Thigh clearance	151.54	15.87	149.0	17.7	2.5**	1.7
Buttock-Popliteal Length	479.04	24.62	439.0	29.0	40.0**	9.1
Buttock-Knee Length	559.83	26.60	547.0	30.0	12.8**	2.3
Popliteal height	403.75	21.29	355.0	24.0	48.8**	13.7
Shoulder breadth	431.76	34.21	389.0	27.0	42.8**	11.0
Elbow breadth	435.18	54.52	481.0	48.0	-45.8**	-9.5
Hip width	390.66	32.04	364.0	28.0	26.7**	7.3

*<0.05. **<0.01

Table 5.4. Anthropometric Male data from the 2016 and 1995 studies

Anthropometric Dimension (mm)	2016		1995		Difference	
	Mean	SD	Mean	SD	Absolute value	%
Weight (Kgs)	81.4	13.1	69.3	11	12.1**	17.5
Stature	1710.0	65.0	1688	67	22.0**	1.3
Eye height standing	1600.7	63.8	1584	67	16.7**	1.1
Shoulder height standing	1416.2	59.9	1392	60	24.2**	1.7
Elbow height standing	1041.9	48.3	1045	49	-3.1*	-0.3
Knuckle height	758.8	38.3	742	45	16.8**	2.3
Sitting height	912.3	35.0	897	35	15.3**	1.7
Eye height sitting	803.5	33.3	794	42	9.5**	1.2
Shoulder height sitting	619.0	28.5	602	38	17.0**	2.8
Elbow height sitting	244.6	24.4	254	40	-9.4**	-3.7
Abdominal depth	267.6	39.4	256	40	11.6**	4.5
Thigh clearance	165.4	14.9	140	18	25.4**	18.1
Buttock-Popliteal Length	496.5	24.6	460	31	36.5**	7.9
Buttock-Knee Length	590.4	27.5	575	36	15.4**	2.7
Popliteal height	436.2	23.2	401	28	35.2**	8.8
Shoulder breadth	475.0	30.1	414	32	61.0**	14.7
Elbow breadth	487.7	47.8	519	49	-31.3**	-6.0
Hip width	362.5	26.1	344	29	18.5**	5.4

*<0.05. **<0.01

It can also be seen in Tables 5.3 and 5.4 that five dimensions showed a decrease. It is interesting to note that two dimensions showed a decrease for both genders. Those dimensions were Elbow breadth (F: -9.5% M: -6%) and Elbow height sitting (F: -8.3% M: -3.7%). If we focus exclusively on females, it can be seen in Table 5.3 there was a decrease on two dimensions, Eye height sitting: (-0.4%) and Abdominal depth: (-5.1%). By observing Table 5.4, it can be seen that males showed a decrease exclusively on the Elbow height standing (-0.3%). It comes to attention that one would expect that if Weight and Stature show an increase, segmental dimensions associated to width, breadth, depth and length, should grow equally, however in practice, the fact is that it is possible to see a decrease. In the case of Hanson et al. (3), after 48 anthropometric dimensions were collected and compared against previously collected dimensions used in Swedish anthropometrics, the authors found a decrease in 14 dimensions, 11 for women and 3 for men. The most significant changes were seen on dimensions associated with Weight, particularly on women, even when the weight for Swedish adult women increased more than stature, such as Abdominal depth sitting (F: -4% M: 4.3%) and Thigh clearance (F: -5.2% M: -3.3%) (3).

Thus, there may not necessarily exist a direct relation between Weight/Stature and their related segmental dimensions as stated by Steenbekkers (21). It came to the surprise of the research group that some dimensions had a negative secular growth on female workers only (eye height and abdominal depth), male workers only (elbow height sitting) and for both female and male workers (elbow height sitting and elbow breadth). One possible explanation could be that the 1995 sample had taken workers from only three industrial sectors, thus influencing somehow the results. Other possible explanation of the variations could be the measuring technique and the subject posture while being measured. The authors of the current paper observed that several subjects modified their posture in order to accommodate the "arms" of the anthropometer while being measured. For example, it was quite often that one of the researchers had to lower the subjects' arm while measuring elbow height sitting, since the subject shrugged their shoulder when the anthropometer touched the elbow. In fact, according to Fisher and Byrne (49), women are more sensitive to perceive adjacent overlap as an intrusion into their personal space, explaining in part the fact why women had more negative trends than men.

Regarding elbow breadth, it is possible that the training in 1995 allowed less pressure between arms and body and therefore larger values. Also, while using only two observers that interchange data registration and measurements during the survey could have induced error – it is known that the person performing one task should stick to it to ensure more reliable results. Additionally, on the 1995 sample the lack of a third observer could have made it more difficult to address any postural deviations of the participants while being measured (50). The researchers involved in the current study took part of a rigorous pre-measurement training session and had expert supervision during training, thus any deviation from measurement protocol was immediately addressed and corrected. The baseline study from 1995 did not describe any quality protocols. Even if this was not the reason for the variation of some measurements, it highlights the importance of having well trained observers and supervisors, as well as a well-established protocol to prevent and correct any deviation.

By looking at Tables 5.3 and 5.4, it can be seen that Stature (F: % 2.9 M: 1.3%) had an increase that was considerably smaller than the Weight increase (F: % 10.3 M:17.5 %) for both genders. These results are similar to the ones obtained for US civilians (30), Dutch university students (29) and Swedish adult populations (3). This finding indicates that the Chilean adult population is following the global trend of obesity (51), which has been constantly increasing (52). These findings clearly adds up to the trend of increasing mass relative to stature of individuals worldwide, which will impact on the design of seat dimensions (29).

The positive secular growth experienced by Chilean workers is a finding that was already expected, as it has occurred in other countries and populations as well (20). From Figure 5.2 it can also be seen that Chilean workers had an average increase in stature of about 15 mm per decade, specifically 20 mm per decade for women and 10.5 mm per decade for men. This finding was also seen in an anthropometric survey in Chilean schoolchildren, where girls had a higher secular growth than boys (34). According to Castellucci et al. (34), there was a secular growth per decade of 14 mm and 11 mm for girls and boys, respectively. The stature increase was also associated with an increase in popliteal height, which was 10 to 30 mm higher; hip width that was 22 mm higher and buttock-popliteal distance that was 21 mm higher.

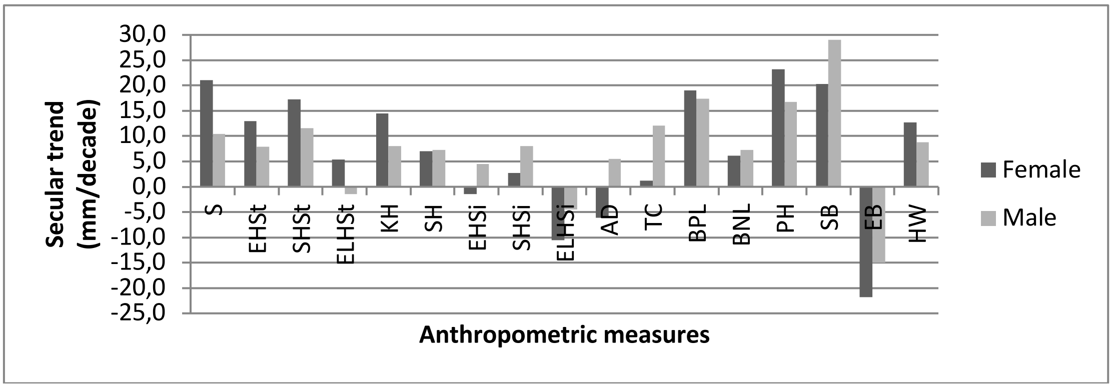

Figure 5.2. Secular trend per decade in the anthropometric measurements.
Stature (S), Eye height standing (EHst), Shoulder height standing (SHst), Elbow height standing (ELHst), Knuckle height (KH), Sitting height (SH), Eye height sitting (EHsi), Shoulder height sitting (SHst), Elbow height sitting (ElHst), Abdominal depth (AD), Thigh clearance (TC), Buttock-Popliteal Length (BPL), Buttock-Knee Length (BNL), Popliteal height (PH), Shoulder breadth (SB), Elbow breadth (EB), Hip width (HW)

These findings show a very particular phenomenon, since despite the fact that Chilean male workers are taller than female workers, the latter experienced a stature increase that doubled the one experienced by males over the last 2 decades. These results conflict with those presented by Cole (20), who indicated that in the 20th century, the women's trend has been less clear than the men's trend. This has also been the case among Swedish adults (3), where stature has increased 0.9 mm/year for females and 1.4 mm/year for males. These numbers are in agreement with general secular trend growth rate figures (36) and with the growth rate of Italians (24). Our findings are somehow similar to the ones obtained by Agarwal et al. (53), who concluded that women experienced a bigger increase in their stature than men. Although focused on children and adolescents, they reported growth parameters on over 20,000 children from 23 schools in various cities in India, showing that in children and adolescents, a secular trend was reported (19 years) revealing an increase in average stature of 21 mm for boys, and 27 mm for girls per decade at 17 and 14 years, respectively.

One possible explanation for the clear Stature increase of Chilean women, could be that gender equality has improved in Chile since the country got open to democracy in 1990, with many social programs focusing on women and girls only, such as women’s health, education scholarships, entrepreneurship funds, social security, and other social benefits (54). Since male workers had an increase in their stature and have been somehow “privileged” compared to women, it is likely that females caught up by expressing their biological potential through the last two decades. This would make sense, since relevant research on the subject states that deprivation and adverse conditions have a negative effect on human growth, such as inability to access good healthcare, education, nutrition and a higher incomes (20,32,55,56). Another author found similar trend in children and adolescents in India, where women’s education programs and social benefits had increased life expectancy above national average in the Kerala province, which affected positively the growth of children (57).

It would be interesting to see 10 year from now, the effects on secular trend of social programs addressed to women, in order to see their impact on women’s growth compared to men. Strong equity policies focused on women have been are currently implemented in Chile since the last 4 years, including the creation of a Women`s and Gender Equity Ministry, two years ago (58). For example, a study conducted by Schwekendiek and Jun (59) analyzed, among other factors, the income per capita, and the consumption of meat and milk in South Korea, and compared the Korean male adult stature trend with the previously stated variables. We believe that better living conditions are a possible explanation for the observed trend in Chile, since transition of health problems related to child malnutrition have been replaced with chronic non-transmissible illnesses associated with obesity (60). This is typical and coherent with the obesity epidemic that affects many countries that have reached or are in the process of achieving better living standards (20,56). Also Cole (20) suggested that since the 90’s, stature in developed countries is generally stable compared to Weight. In the case of Chilean adult working population this trend can also be seen, even when stature increased, it was considerably smaller than the Weight increase, thus showing that Chile is experiencing a secular change trend somehow similar to developed countries.

Tables 5.3 and 5.4 can also show that the dispersion of the dimensions was higher on women, since the standard deviations showed an increase on eight dimensions for women (Weight, Eye height standing, Shoulder height standing, Elbow height standing, Abdominal depth, shoulder breadth, Elbow breadth and hip width) and only on Weight for men. This presents a challenge for future designs focused specially on women. The stature and segmental increases on Chilean working women's anthropometrics and their dispersion, could definitively have an impact on women products or in products that use male anthropometrics for design but are also used by women, such as firefighting gear (61).

Top notch anthropometric research has been used for delivering databases in order to designs that are safe and efficient. This has been the case for even with specific populations, such as Brazilian air force personnel (15), Colombian flower farmers (16), electricity workers (41) and even special populations (8). Hitherto the dimensions used for designing or purchasing equipment for Chilean workers was more than two decades old, therefore the data presented on this study makes a contribution to any Occupational Health and Safety/ergonomics practitioner, designer or manufacturer aiming to introduce any product or work station that has Chilean workers as end users. Finally, for future work will be important to gathered dynamic anthropometric data, such as range of motion, angle between body parts, spinal curvature, center of pressure and so on (62).

5.4. Conclusions

Chileans female and male workers have more Weight (F: 6.2 M: 12.1 kg) and are taller (F: 44.2 M: 22.0 mm) than in 1995. However, Weight increased more (F: 10.3% M: 17.5%) than Stature (F: 2.9% M: 1.3%), which is coherent with the observed global obesity trend. Women have experienced a Stature increase are nearly the double of the one observed for men. These findings are interesting and shows that it might be worth to conduct further research that allows to understand why women had a higher secular growth in Stature than men (fact also observed on Chilean school children). The research team believes that this may be attributed to better living conditions, social programs and education access that addressed specifically women. Regarding gender differences among Chilean workers, it was observed that male workers have larger measurement values than women, with the exception of Hip width, which is common on all populations. In addition to Stature, other anthropometric measures have also increased significantly during the last two decades, such as Popliteal height (F: 48.8 M: 35.2 mm), Hip width (F: 26.7 M: 18.5

mm), Buttock-popliteal length (F: 36.5 M: 40 mm), Buttock-knee length (F: 12.8 M: 15.4 mm), Shoulder height standing (F: 36.1 M: 24.2 mm), Knuckle height (F: 30.4 M: 16.8 mm), among others. Those segmental dimensions that experienced a greater increase are highly associated to seated design match.

A wide range of recent studies have emphasized the importance of up to date anthropometrics in order to produce effective and safe designs. Thus, the data presented in this study shows the need to review designs for Chilean workers, especially public transport seating and office furniture. Other designs such as industrial workstations and personal protective equipment or elevators should also be reviewed in order to understand the level of match covered of the Chilean workers. Finally, we hope that designers and the Occupational Health and Safety community can disseminate and use the data of the 2016 data collection campaign and presented in this paper, in such a way that they can be applied to specific and safer designs for Chilean workers.

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CHAPTER 6| Gender inequality and height sexual dimorphism in Chile

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Chile has experienced significant improvements in its economy; thus, a secular trend in height has been observed in its population. Gender equality has also improved hand in hand with active policies addressing the gender gap and overall economic improvement. The current study aims to examine changes in sexual height dimorphism in 4 samples of Chilean male and female working age subjects and establish associations with gender equality and welfare. Sexual height dimorphism was calculated and compared with gender equality and overall welfare indicators between 1955 and 1995. Sexual height dimorphism reduction was strongly associated with more gender equality and some general welfare indicators, such as the infant mortality rate. Gross domestic product per capita was not associated with sexual height dimorphism; however, it showed significant associations with gender equality indicators. Overall, the gender gap has been reduced in Chile, which can be observed through improvements in gender equality indicators and a reduction in height dimorphism, mainly in areas associated with women's health. However, gender equality is still far behind in terms of female labour participation and women in political power, which requires attention and further improvements.

Keywords: height; dimorphism; gender

6.1. Introduction

Height has been used in several studies to assess variations in social and environmental factors of humans, such as education, access to healthcare, sanitary conditions, income level and social class (Silventoinen et al., 2001; Cardoso & Caninas, 2010; Blum, 2014; Huang et al., 2015; Krzyżanowska & Borysławski, 2015; Grasgruber et al., 2016; Borrescio-Higa et al., 2018). It has been widely accepted that height can either increase or decrease in a given population, mainly depending on the scarcity or abundance experienced by those particular populations, thus communicating the overall outcome of a society's state of development (Tanner, 1986). For example, height is often used to study the impact of living conditions during childhood, which, when adverse, can hinder adult height (Cole, 2003). Additionally, changes in anthropometric dimensions emphasize health-related living conditions that traditional monetary indicators cannot entirely cover (Koepke et al., 2018).

There are several causes that are related to human growth, some of the most relevant being nutrition, exposure to infectious diseases and mother-child interaction (Cole, 2000). Even though these relationships are complex in nature, they are often interdependent with other social variables, such as having more education, better jobs and opportunities in general (Enjezab et al., 2015; Wronka, 2015; Blackstone, 2017; Kheirouri & Alizadeh, 2017).

It is estimated that approximately 20% of the outcome is driven by the cumulative net nutritional history of a population (Silventoinen, 2003; Deaton, 2007; Mcevoy & Visscher, 2009;); therefore, not only biological preconditions but also socio-economic and cultural factors, including females' situation in society, have to be taken into account to understand the mean height outcome of a population and the potential changes in health-related well-being (Koepke et al. 2018).

These changes over time in height and other variables across populations are called secular trends (Hauspie et al., 1996). Secular trends in anthropometric dimensions, such as height, have been experienced by several populations (Hauspie, R., Vercauteren, M., Susanne, 1996; Barroso et al., 2005; Arcaleni, 2006; Matton et al., 2007; Webb et al., 2008; Baynouna et al., 2009; Cardoso & Caninas, 2010;

Schwekendiek & Jun, 2010; Tomkinson, Clark, & Blanchonette, 2010; Bielecki, Haas, & Hulanicka, 2012; Dos Santos et al., 2014). In the case of Chile, positive secular trends in height have been observed in school children (Castellucci et al., 2015) and the general population (Borrescio-Higa et al., 2018), where the improvement in overall living conditions is most likely the related cause. Secular changes have been associated with overall social well-being indicators, such as gross domestic product (GDP) per capita increments and child mortality decrements (Bozzoli et al., 2007; Borrescio-Higa et al., 2018). Both indicators have accordingly improved in Chile; in fact, this country has experienced the worldwide trend of developed countries, whereby undernourishment has been replaced by obesity and a high prevalence of obesity-related chronic illnesses (Muzzo et al., 2004).

In general, it is assumed that women are shorter than males and that their secular height increase is lower (Cole, 2003). It is believed that genetics is relatively unimportant, mainly because affluent children in developing countries grow similarly to those in developed countries (Cole, 2000). Evolutionary theories (i.e., males are taller to compete over fewer females) have also been questioned, since it is believed that other ecological factors can contribute more to height dimorphism, such as social gender equality and the behaviours of certain societies that have a larger impact on height differences between the sexes (Touraille, 2013). The impact of female living conditions on development and overcoming poverty in patriarchal societies has been recognized as highly relevant, as in these societies a potentially powerful reason for female discrimination is that investment in sons brings greater market returns (Strauss & Thomas, 1995); therefore, in some cases, female physical work in the household is not considered as deserving particular food support (Koepke et al., 2018). Chile has experienced several changes regarding gender equality, starting in the last 20 years with an explicit policy of gender equality promotion that has been mainly mediated by the role of women's organizations at the end of the military regime, which had capacity to install in the public agenda the idea that real democracy was not possible without promoting gender equality at the same time (PNUD, 2010).

Height can also highlight inequality within a society, and it has been used to show that when there is a height divergence between different ethnic groups, there is probably an imbalance in living conditions (Uvin, 1999). Moreover, since health inequality variables are intrinsically essential, it is useful to use height dimorphism as an indicator (Deaton, 2003). As an outcome measure, mean height allows comparisons across different sources, such as between females and males (Koepke et al., 2018). Distribution of height is used as an approximate determinant of inequality in the case where monetary measurements are hard to find or definitively do not exist, as this measure complements conventional inequality indicators. Final average height and height inequality reflect a birth cohort's net nutritional intake during childhood and youth; hence, it is a primary indicator of the nutritional and health statuses of a population (Blum, 2014), therefore average values give a clear illustration of well-being, while inequality measures highlight differences in living standards (Silventoinen, 2003; Blum, 2014; Mark, 2014). Conventional income data from earlier time periods and from developing countries are often weak in quality and low in availability – two reasons for the popularity of anthropometric data among economic historians and development economists and while a correlation between income inequality and height inequality does exist, this correlation is not perfect, since some important inputs to biological living standards such as public health measures, for example, are often financed by public funds or statutory insurance (Blum, 2014).Height inequality captures important biological aspects of inequality and may lead to new insights while serving as a countercheck for conventional indicators(Blum, 2014). Sexual height dimorphism has been used by many authors in order to address gender inequality and its expression through anthropometrics, since it can measure multiple contributions to the improvements in living conditions, both formal and informal ones (Smith, 1999; Silventoinen et al., 2001; Silventoinen, 2003; Blum, 2014; Mark, 2014; Som et al., 2014; Wronka, 2015).

Several indicators have been created to account for gender equality across nations, whereby some countries, such as Sweden, Finland and Denmark, often rank high, while others such as Yemen, Afghanistan and Lesotho, rank low on gender equality (Mark, 2014). From a regional perspective, Latin America takes the third place in gender parity (70.8%), after North America (72.5%) and Western Europe (75.8%) (WEF, 2018). Chile has experienced substantial improvements in its economy and overall living conditions in the last 30 years, with poverty rates famously decreasing and household income, school and higher education assistance rates increasing, together with having a fairly stable democratic system (PNUD, 2017). However, even

though relevant development indicators of the country have improved, Chile is still a very unequal country, especially when considering gender differences regarding income, paid and formal work as well as financial independence (PNUD, 2010; ComunidadMujer, 2018; WEF, 2018).
The aim of this study is to analyse height gender dimorphism across time in Chile based on four samples and to establish possible explanations for the differences using two dimensions, namely, gender equality and general welfare indicators.

6.2. Methods

Four samples were used. The data were published in 1974, 1990, 2012 and 2016. The first three corresponded to data from school populations and the latter from workers, all of them collected by independent research groups. All of the included samples were part of larger projects aiming to obtain anthropometric measurements, with a focus on health or ergonomics and design. They all obtained data through direct measurements performed by teams of 2 or three evaluators.

6.2.1. Samples

The 1974 sample was extracted from a study conducted in Santiago de Chile, with 1,238 females and 1,347 males aged 6 to 20 years old to obtain anthropometric data to assess growth and health (Avendaño et al., 1974). The average heights of those aged 17 and older were considered in the current study (n: 288, 144 males and 144 females). More information useful for the current study was rarely reported; however, regarding the socio-economic background, the authors reported that 32% of the females and 33% of the males had fathers occupied as an "employee" and a mother as a "housewife”. The rest of the groups fell into the "operator-housewife" and "little business owner-housewife" categories. No information regarding sampling strategies was provided. Specific average heights can be seen in detail in Table 6.1.

Table 6.1. Birth year, average height and corresponding sample

Birth cohorts	Female			Male		
	n	Mean	SD	n	Mean	SD
1955[a]	57	154.9	4.6	57	169.4	5.2
1956[a]	57	154.9	4.6	57	168.6	5.3
1962[d]	66	157.2	5.9	390	169.1	6.3
1972[d]	102	158.7	6.3	567	170.4	6.5
1973[b]	32	157.9	5.9	32	171.1	6.8
1982[d]	141	160.2	6.0	712	171.9	6.6
1992[d]	141	160.2	6.0	661	172.1	6.0
1994[c]	71	159	5.5	69	170.4	6.2
1995[c]	103	160.6	6.8	102	171.1	6.5

a: sample from 1974; b: sample from 1990; c: sample from 2012; d: sample from 2016

The 1990 sample consisted of a total of 842 participants (415 females and 427 males) aged between 6 and 18 years old whose data were collected in the city of Concepción. aiming to collect dimensions to design school furniture. In this study. the authors reported that 20% came from a high socio-economic level. 46% from the middle socio-economic level and 34% from the lower socio-economic level (Gutiérrez & Apud. 1992). The average height of those aged 17 and older was considered in the current study (n: 64, 32 males and 32 females). It was reported that evaluators spent considerable time practising until measurements were consistent and followed a standardized procedure. Specific average heights can be seen in detail in Table 6.1.

The 2012 sample was a stratified representative sample of 1,397 females and 1,681 males with ages ranging from 5 to 19 years (11.7±3.5) collected in the Valparaíso region for designing school furniture (Castellucci et al., 2015). The sample was composed of 26.5%, 63.2% and 10.3% of participants from low, medium and high socio-economic levels, respectively. The 2012 sample was collected by the authors of the current paper. The average height of subjects who were 17 and 18 years of age was used (n=345, 171 males and 174 females). Evaluators spent considerable time practising until measurements were consistent and followed a standardized procedure. Specific average heights can be seen in detail in Table 6.1.

The 2016 sample was collected by the authors of this article as part of a larger research project and included the collection of a total of 32 anthropometric measures with a focus on ergonomics. Data were collected on 2,946 workers (600 females and 2,346 males) from two of the most populated regions of Chile (Valparaíso and Metropolitana) distributed across 9 economic activity sectors (Agriculture and fishing; Mining; Manufacturing; Electricity; Construction; Commerce; Transport and communications; Financial services; and Communal and personal services).

The measurement process was carried out by a team of six physiotherapists divided into two teams. Before starting the survey, the measurement teams underwent a one-week training session, including a theoretical approach to anthropometrics and practical instruction lectures. Specific average heights can be seen in detail in Table 6.1.

6.2.2. Statistical analysis

First, data corresponding to the average height of subjects aged 17 and above were extracted from the 1974, 1990 and 2012 samples. This was done since at those ages, the subjects were probably closer to their definitive adult height; girls usually reach adult height when they are close to 15 years old and boys 17 years old (Susman & Rogol, 2004; Papalia et al., 2009). Although it varies among countries, the beginning of puberty and thus of the final growth spurt can be recognized as being initiated by menarche in girls and secondary sexual characteristics in boys and lasting for nearly 2 years (Cole, 2000, 2003; Wells, 2012; Ezzati & NCD-RisC, 2016). Chile has experienced a reduction in the age of puberty appearance, mainly due to improvements in living conditions, as it has been reported that well-nourished children from families with good socio-economic conditions experience the growth spurt earlier than malnourished children from families with poor living conditions (Wronka et al., 2015). Most Chilean girls experience menarche at 13 years old and boys experience the appearance of secondary sexual characteristics at 15 years old (Valenzuela & Avendaño, 1979;

Ivanovic & Ivanovic, 1988; Burrows et al., 2010). These findings have been reported in other populations (Cole, 2000, 2003). Therefore, it could be considered that 17 years is an age when both girls and boys in Chile attain definitive height. Therefore, 17 and above ages were used since that way the researchers could compare cohorts considering final adult height, not worrying that heights of a particular cohort varied significantly after it was measured. Sexual height dimorphism, as stated previously , can be attributed to multiple reasons, mainly due to the improvements experienced in nutrition, health , education and work, thus female living conditions and corresponding potentialities are acknowledged as key issues for development and overcoming poverty (UNICEF, 2018a). Trends in overall well-being, measured by mean adult height, especially for females, can help to clarify the unprecedented increase in the standard of living and development (Koepke et al., 2018). Sexual height dimorphism (DIM) was calculated using average heights of each age cohort according to the following formula, as used by (Wells, 2012):

DIM=(Height male- Height female)/Height female*100.

This allows us to account for percentage variation, using the male dimension as a reference. Each percentage of sexual dimorphism calculated was then plotted to the corresponding year of the birth of the sample in question. This was done for the 1974, 1990 and 2012 samples, since only age and the number of subjects (not individual data) were available for a particular birth cohort. In the case of the 2016 sample, for which age ranges were available together with individual data, the year corresponding to the middle point of the range was selected. For each of those years, gender inequality and overall society well-being indicators were retrieved from Chilean and international official documents and websites. In some cases, specific year indicators were not available; in those cases, the nearest year indicator was used (see Table 6.2).

Table 6.2. Data sources used and technical considerations

Dimension	Indicator	Source	Technical considerations
Gender inequality	Global fertility rates (GFR)	(CELADE-CEPAL-UN, 2013)	The total number of children that would be born to each woman if she were to live to the end of her child-bearing years and give birth to children in alignment with the prevailing age-specific fertility rate.
	Birth rate (BR)	(DEIS-MINSAL, 2012)	Birth rate is the number of live births occurring in the population of a given geographical area during a given year, per 1,000 mid-year total population of the given geographical area during the same year.
	Gender Inequality Index (GII)	Own elaboration for years with available information	Procedure and methods according to (UNDP, 2018).
	Maternal mortality ratio (MMR)	(Koch et al., 2012)	The maternal mortality rate is the number of women who die during pregnancy and delivery per 100,000 live births. The data are estimated according to a regression model that uses information on fertility, birth attendants and HIV prevalence. There is no data for 1955 and 1956 is replaced by data from 1957.
	Adolescent birth rate (ABR)	(CELADE-CEPAL-UN, 2004) (WorldBank, 2019a)	Adolescent mothers are the percentage of women between 15 and 19 who already had children or who are currently pregnant. Data from 1955 and extracted from CELADE-CEPAL-UN. Data of 1956 is replaced by data from 1960. The source of the other years is the World Bank.
	Share of seats in the parliament (SSP)	Own elaboration based on G. U. Valenzuela, (1992)	Between 1973-1989 there was a military dictatorship that closed the parliament.
	Population with at least some secondary education (PSE)	(Barro & Lee, 2016)	The percentage of population who had access to higher education. The year 1962 is replaced by 1960; 1962 is replaced by 1972; 1973 is replaced by 1975; 1982 is replaced by 1980; and 1992 is replaced by 1990.
	Labour force participation rate (LFPR)	(WorldBank, 2019e)	The percentage of total population age 15+ who are employed. The year 1962 is replaced by 1960. The year 1972 is replaced by 1970.
Overall welfare	Infant mortality rate (IMR)	(CELADE-CEPAL-UN, 2013)	Deceased children under one year for every 1,000 live births in a given year.
	Gross domestic product per capita (GDPc)	(WorldBank, 2019b)	Dividing a country's GDP for a particular period by its average population for the year.

Global indicators of welfare, such as the infant mortality rate (IMR) and gross domestic product per capita (GDPc), were used to analyse how those indicators were associated with sexual dimorphism. Gender inequality indicators are quite recent; therefore, they are often not readily available, especially when looking further back in time, and the same occurs with women specific information regarding work and education and other basic demographic information (Koepke et al., 2018). One of the latest indicators used is the Gender Inequality Index (GII).

The GII considers several dimensions that account for gender inequality, such as the maternal mortality ratio (MMR), adolescent birth rate (ABR), share of seats in the parliament (SSP), population with at least some secondary education (PSE) and labour force participation rate (LFPR) (UNDP, 2018). The reproductive health dimension is an indexed value of maternal mortality ratios and adolescent fertility rates. The empowerment and labour market dimensions utilize the ratios of male to female parliament members, ratios of male to female population with at least secondary education, and the ratio of male to female labour force participation. In the case of PSE and LFPR, the net differences were calculated between female and male populations to assess net variations (DIFPSE and DIFLFPR, respectively), where positive values indicate a larger male participation and negative values indicate the opposite; thus, negative values convey more gender equality on the dimension. Index values range from 0 to 1, with lower values representing near-perfect gender equality and greater values representing greater levels of gender inequality (Mark, 2014; UN, 2018). The GII was calculated for those years where the data were available. Since information was not available for all variables to calculate the GII, parts of the GII, together with similar available indicators such as global fertility rates (GFR) and the birth rate (BR), were also used. This choice was made because reproductive health is one of the main dimensions that make up the GII, since it can somehow account for women's control over their bodies; as has been shown, in highly patriarchal societies women have more children due to a lack of empowerment (Mark, 2014; Enjezab et al., 2015) and the use of reproductive health services by women is a function of the availability of facilities and gendered inequalities that influence women's access to social and economic resources, freedom of movement and decision-making power in matters that are significant to their well-being (Banda et al., 2017).

Overall welfare indicators were IMR and GDPc, which have also been used to assess societies' progress and have been associated with height variations (Bozzoli et al., 2007; Borrescio-Higa et al., 2018). Additional details of the sources and technical notes on the indicators can be seen in Table 6.2.

After gender equality and welfare indicators were retrieved or calculated, a single point was determined for each of the years selected. Finally, Spearman's correlation coefficients were used to compare sexual height dimorphism, gender inequality and the society's overall welfare indicators. In some cases, the complete series for GII were not calculated because of missing information. In those cases, correlations were carried with relevant subcomponents of the GII. Since only 9 points across time were retrievable, the contribution of each point to the correlation was checked using a Bonferroni influence case analysis in order to check abnormal contributions of a particular data point (Fox & Weisberg, 2011)

6.3. Results

Table 6.3 contains the years and indicators used. It was noted that indicators reflecting a reduction in gender inequality (MMR, ABR, SSPF, PSEF, DIFPSE, LFPRF, DIFLFPR, GII, BR, GFR) show a tendency to decrease with time, showing an improvement in gender equality. The same can be observed for the overall living conditions indicators, where GDPc has consistently increased and IMR has decreased since 1955. From Table 6.3, it is possible to note that sexual height dimorphism (DIM) has decreased from 9.4% in 1955 to 6.5%, indicating an increase in average female height when compared with males.

Table 6.3. Gender indicators, general well-being indicators and sexual height dimorphism (1955-1995)

Year	MMR	ABR	SSPF	PSEF	PSEM	DIFPSE	LFPRF	LFPRM	DIFLFPR	GII	DIM	BR	GFR	GDPc	IMR
1955	N/A	80	0.006	20.5	21.2	0.59	N/A	N/A	N/A	N/A	9.4	35.1	4.9	N/A	120.3
1956	270.7	88.4	0.006	N/A	N/A	N/A	N/A	N/A	N/A	N/A	8.8	36	5.4	N/A	118.3
1962	259.5	89.3	0.034	22.1	22.7	0.58	22.74	85.1	62.4	0.68	7.6	37.9	5.4	669.6	109.0
1972	113.5	85.1	0.06	26.5	26.8	0.28	21.66	79.5	57.8	0.61	7.3	28	4.0	1067	68.6
1973	113.6	82.8	0.093	26.2	26.2	-0.04	N/A	N/A	N/A	N/A	8.4	27.5	3.6	1667.5	68.6
1982	51.8	67.1	N/A	27.1	26.9	-0.14	27.37	68.3	40.9	N/A	7.3	23.4	2.7	1884	23.7
1992	30.9	64.9	0.058	38.4	38.4	0.00	33.41	75.5	42.1	0.47	7.4	21.5	2.3	3288.55	14.1
1994	25.6	63.8	0.075	N/A	N/A	N/A	35	76.6	41.6	N/A	7.1	20.4	2.2	4045.6	14.1
1995	31.2	63.2	0.075	39.5	39.3	-0.18	33.93	75.2	41.2	0.45	6.5	19.4	2.2	5137.3	11.5

MMR: maternal mortality ratio; ABR: adolescent birth rate; SSPF: share of seats in parliament (% held by women); PSEF: population with at least some secondary education, female; PSEM: population with at least some secondary education, male; DIFPSE: difference between PSEM and PSEF; LPRFF: labour force participation rate, female; LPRFM: labour force participation rate, male; DIFLFPR: difference between LFPRM and LFPRF; GII: Gender Inequality Index; DIM: height dimorphism(%); BR: birth rate; GFR: global fertility rate; GDPc: gross domestic product per capita; IMR: infant mortality rate. N/A: information not available.

Table 6.4 shows the results of the Spearman correlations. Height dimorphism (DIM) is correlated with all variables; however, the only ones that showed statistically significant correlations were MMR (moderately high: 0.7857; $p < 0.05$), ABR (moderately high 0.6667; $p < 0.05$), PSEF (strong: -0.8571; $p < 0.05$), BR (moderately high: 0.7833; $p < 0.05$), GFR (strong: 0.8167; $p < 0.01$) and IMR (strong: 0.8908; $p < 0.01$). All the previously mentioned variables were correlated at least at moderately high levels with height dimorphism. The net differences in DIFPSE (0.7500; p= 0.052) and DIFLFPR (0.7714; p=0.07) showed moderately high correlations; however, the significance levels were barely above limits. Table 6.4 shows that GDPc was positively correlated with indicators for which females improved their participation, such as SSPF (moderate: 0.5218; $p < 0.05$), PSEF (strong: 0.9429; $p < 0.01$), and LFPRF (0.8857; $p < 0.05$). GDPc was negatively correlated with indicators that experienced a decrease with time or a decrease in the gap, such as GII (strong:-1.0000; $p < 0.01$) and some of its components, such as ABR (strong:-1.000; $p < 0.05$), DIFPSE (strong:-0.8286; $p < 0.05$), DIFLFPR (moderately high:-0.6571; $p < 0.05$). GDPc also showed negative correlations with BR (strong: -1.0000; $p < 0.01$), GFR (strong: -1.0000; $p < 0.01$) and IMR (strong: -0.9820; $p < 0.05$). IMR showed similar patterns where it was positively correlated with GII (strong: 1.0000; $p < 0.01$) and some of its components, such as MMR (strong: 0.9157; $p < .01$), ABR (strong: 0.8068; $p < 0.01$), DIFPSE (strong: 0.8649; $p < 0.05$), and DIFLFP (moderately high: 0.6377; $p < 0.05$). IMR also showed a positive correlation with BR (strong: 0.9244; $p < 0.01$) and GFR (strong: 0.9412; $p < 0.01$).

Table 6.4. Spearman's correlation matrix

	MMR	ABR	SSPF	PSEF	DIFPSE	LFPRF	DIFLFPR	GII	DIM	BR	GFR	GDPc	IMR
MMR	1												
ABR	0.8809*	1											
SSPF	-0.5045	-0.4819	1										
PSEF	-0.9428*	-0.7500	0.6000	1									
DIFPSE	0.5428	0.6428	-0.8857*	-0.8214*	1								
LFPRF	-0.8857*	-0.8857	0.6668	0.9000*	-0.8000*	1							
DIFLPR	0.4857	0.6571	-0.8720	-0.7000	0.9000*	-0.5428	1						
GII	0.8000	1.0000	-0.8000	-1.0000**	1.0000*	-0.8000	1.0000*	1					
DIM	0.7857*	0.6667*	-0.6265	-0.8571*	0.7500	-0.6571	0.7714	0.8000	1				
BR	0.8809*	0.9500**	-0.7229*	-0.9285**	0.8571*	-0.8857*	0.6571*	1.0000**	0.7833*	1			
GFR	0.9047*	0.9333**	-0.7590*	-0.9285**	0.8571*	-0.8857*	0.6571*	1.0000**	0.8167**	0.9833**	1		
GDPc	-0.8571*	-1.0000**	0.5218*	0.9429**	-0.8286*	0.8857*	-0.6571*	-1.0000**	-0.7500	-1.0000**	-1.0000**	1	
IMR	0.9157**	0.8068**	-0.7378*	-0.9910*	0.8649*	-0.8407*	0.6377*	1.0000**	0.8908**	0.9244**	0.9412**	-0.9820*	1

* *

* p < .05, ** p < .01. MMR: maternal mortality ratio; ABR: adolescent birth rate; SSPF: share of seats in parliament (% held by women); PSEF: population with at least some secondary education, female; DIFPSE: difference between PSEM and PSEF; LPRFF: labour force participation rate female; DIFLFPR: difference between LFPRM and LFPR; GII: Gender Inequality Index; DIM: height dimorphism; BR: birth rate; GFR: global fertility rate; GDPc: gross domestic product per capita; IMR: infant mortality rate.

After the Bonferroni analysis, only one atypical observation was found, corresponding to SSPF in 1973. After removal of that value, a new Spearman correlation was calculated, indicating that SSPF is negatively correlated (strong: -0.9819805; p < 0.01) with height dimorphism. The overall results of the Bonferroni test are shown in Table 6.5

Table 6.5. Bonferroni test results

Indicator	Atypical case observation number (year)	Re-student	Un/adjusted p-value	Bonferroni p	Spearman's after removing atypical value
MMR	3 (1962)	-2.142852	0.08501	0.68008	--
ABR	1 (1955)	2.706137	0.035287	0.31758	--
SSPF	**5 (1973)**	**4.86662**	**0.0046064**	**0.036852**	**-0.9819805****
PSEF	1 (1955)	2.286859	0.084148	0.58903	--
DIFPSE	1 (1995)	2.002923	0.11573	0.81011	--
LFPRF	9 (1995)	-3.46417	0.040517	0.2431	--
DIFLFPR	9 (1995)	-3.999309	0.028021	0.16813	--
GII	7 (1992)	8.768255	0.072293	0.28917	--
BR	3 (1962)	-3.390857	0.01466	0.13194	--
GFR	3 (1962)	-2.422569	0.051682	0.46514	--
GDPc	5 (1973)	3.771091	0.019586	0.1371	--
IMR	3 (1962)	-2.505987	0.046153	0.41538	--

MMR: maternal mortality ratio; ABR: adolescent birth rate; SSPF: share of seats in parliament (% held by women); PSEF: population with at least some secondary education, female; DIFPSE: difference between PSEM and PSEF; LPRFF: labour force participation rate, female; DIFLFPR: difference between LFPRM and LFPRF; GII: Gender Inequality Index; DIM: height dimorphism (%); BR: birth rate; GFR: global fertility rate; GDPc: gross domestic product per capita; IMR: infant mortality rate. * p < 0.05, ** p < 0.01

6.4. Discussion

First, findings regarding welfare indicators and gender equality will be discussed. In the latter case, other subcomponents addressing health, work, education and political representation of females will be discussed separately.

6.4.1. Gender Inequality Index and height dimorphism

In the current study, all of the gender equality indicators, except for the GII, showed significant correlations. This finding is contrary to the ones by Mark et al. (2014)

regarding GII, since in their case, height variation in females of 96 nations was correlated negatively with the GII. In the current paper, the lack of information did not allow us to calculate the full series of the GII. Historical female information is often scarce, since very often even basic information is missing for the historical female population, as in general, women used to live in an informal and invisible economy (Koepke et al., 2018). Despite this fact, the GII was not correlated with sexual height dimorphism and all the other variables were in the expected way; therefore, the findings suggest that given the information available, gender equality could provide an explanation for the reduction in sexual height dimorphism observed in the samples used. In the case of Mark et al. (2014), regarding the relationships between female height variance and other general- and gender-specific indicators, after factor analysis, it was found that the variance in height was best defined by loading for gender inequality. Other research has suggested that gender equality is a predictor of height for both males and females (Lippa, 2009). In the current study, other health-related indicators, such as the maternal mortality rate, adolescent birth rate, birth rate and global fertility rate, behave accordingly with a reduction in sexual height dimorphism, indicating that in Chile, gender inequality reduction is most likely a major cause of the reduction in sexual height dimorphism. It is worth mentioning that the sexual height dimorphism and gender-specific health indicator gap reduction is a net one, meaning that it does not depend on the improvements associated with the male population but only with the female population, thus providing more arguments for gender equality on this dimension.

6.4.2. Height dimorphism and women's health indicators

The results of the current study show that height dimorphism has experienced a reduction in the studied samples. All variables that were significantly correlated with height dimorphism behaved in the expected way. For example, all of the women's health-related dimensions that somehow account for gender equality, such as the maternal mortality rate adolescent birth rate, birth rate and the global fertility rate, all showed positive significant correlations with height dimorphism (at least at moderate and high levels). These results were expected, since gender inequality is often seen in places where women die while pregnant (or soon after) or where they become mothers earlier and have more children, reflecting less control regarding their bodies and less access to health and contraception (Blackstone, 2016; Kheirouri & Alizadeh, 2017; Morgan et al., 2017;). Women and adolescent girls of reproductive age experience a complex relationship between gender inequality, poverty, pregnancy and childbirth that can expose them to increased risk during child bearing (UNICEF, 2018b). A lack of autonomy to make decisions about one's own health care, low levels of education circumscribing the ability to make informed health care decisions, limited control over financial resources and other factors make it difficult for women to receive the quality needed for healthy pregnancies and deliveries (WHO, 2014; UNICEF, 2018b; WHO, 2018). In fact, the United Nations Human's Rights Council has stated that maternal mortality and, similarly, women's adverse reproductive health outcomes are a reflection of gender inequality (UNHRC, 2011). Latin America has experienced a significant reduction in MMR, from 135 maternal deaths per 100,000 live births in women aged 15 to 49 in 1990 to 68 deaths per 100,000 live births in 2015 (UNICEF, 2018b). In the current study, it is likely that height dimorphism reduction is related to a greater increase in gender equality, as represented by reproductive health and associated decision making. In the case of Chile, for example, MMR has decreased from 270.7 in 1956 to 22.8 in 2015 (DEIS-MINSAL, 2019a), the birth rate has dropped from 35.1 per 1,000 to 12.8 for every 1,000 in 2016 (DEIS-MINSAL, 2019b), and the GFR has experienced a dramatic decrease, whereby Chilean women currently have on average 1.7 children versus 5.0 children in 1955, showing that the overall trend is quite close to developed countries such as Finland, the country that has consistently scored better on gender equality indicators (WorldBank, 2019f).

6.4.3. Height dimorphism and education

In the current research, height and sexual dimorphism were negatively correlated with the percentage of population that has access to secondary education (PSEF female), meaning that the height difference between females and males decreased when more women attended high school. The differences between male and female participation in secondary education (DIFPSE) showed a correlation but barely above significance levels ($p= 0.052$).

Women in developed countries usually postpone child bearing to pursue higher education and work, reflecting more independence and gender equality when compared with countries where the opposite happens (UNICEF, 2018b). Education is a dimension on which Chile has experienced great improvements: for example, an increase in net assistance rates for secondary education in the last two decades, especially for females, where female adolescents had 61,4% and male adolescents 58,5% net assistance rates in 1990, up to 74,8% and 71% in 2015, respectively (ComunidadMujer, 2018). Higher education has experienced even more dramatic improvements, with net assistance rates from 1990 to 2015 ranging from 10.9% to 39.1% in females and from 13.3% to 36.3% for males (ComunidadMujer, 2018). This reduction in the education gender gap is a worldwide trend, even though in many countries, 39.0% of women are illiterate (WEF, 2018). It is known that better education, especially for women, has an impact on them and their offspring (Osmani & Sen, 2003; Maurer, 2010; Enjezab et al., 2015; Blackstone, 2017), thus affecting biological factors such as height through a "health dynasty" transmitted from one generation to another (Silventoinen, 2003; Oxley, 2016). The findings of the current study also show a similar correlation pattern between education and female height obtained by previous studies (Mark, 2014; Koepke et al., 2018;), thus indicating that female average height is increasing and sexual height dimorphism is decreasing.

6.4.4. Height dimorphism, work and parliament seats

The share of seats in parliament of females (SSPF), after the Bonferroni analysis, showed a strong negative correlation with sexual height dimorphism. This was also no surprise, since gender equality usually translates into having more women in parliament seats and managerial positions (WEF, 2018). The labour force participation of females (LPRFF) and the differences compared with males (DIFLFPR) showed a correlation but not within significance limits. This could be due to the many missing historical data points. However, it is worth noting that inactive working age women in Chile have decreased, while male rates have been sustained. For example, women experienced a labour participation increase from 37.4% in 1990 to 56.6% in 2015, while male participation rates were kept relatively constant, ranging from 80.6% to 79.7% from 1990 to 2015 (WorldBank, 2019c, 2019d). Despite the improvements, this shows quite a low participation, being one of the lowest among OECD countries (INE, 2015). The reasons why women are still significantly kept away from the work market in Chile have to do with the fact that often women assume non-paid or informal work, mainly assuming domestic unpaid work. In the case of Chile, despite a reduction from 85.7% in 1990 to 54.7% in 2015, women still state that the reason for not working is related to domestic work and the caring for others (INE, 2015; ComunidadMujer, 2018). In fact, Chilean girls aged between 5 and 17 years still spend 50% or more of their time doing domestic chores than boys of the same age (MINDES-MINTRAB-ILO, 2013). These reasons have also been reported by other authors, who report that girls perform more work than boys at home, both in terms of chores and caring for relatives (UNICEF, 2016, 2017; Koepke et al., 2018). This is a worldwide situation, whereby girls aged 5-9 years old and 10-14 years old spend 30% and 50% more of their time, respectively, on household chores than boys of the same age (UNICEF, 2018a); thus, patriarchal influences start from a very young age for girls. Women and especially girls are more hindered by the time spent on chores, since it stops them from essential development activities such as having time to play, building social networks and focusing on their education, thus reflecting gender inequality that may affect their physical and cognitive development (UNICEF, 2016). The work and parliament share of seats are areas where Chile still has to catch up regarding gender equality, and the legislative power is currently discussing policies to address these areas. The progress in this area, similar to health-related areas, is a net improvement, showing a convergence towards more gender equality.

6.4.5. Height dimorphism and general welfare indicators

Regarding general welfare indicators, the only one that had a strong correlation with sexual height dimorphism was the infant mortality rate (IMR). Gross domestic product per capita (GDPc) showed a strong correlation; however, the significance level was barely above the limits (p=0.052). This finding regarding GDPc and height was also found by other studies, where the contribution of GDPc to height variation was not significant but IMR was (Borrescio-Higa et al., 2018; Bozzoli et al., 2007). Despite this fact, GDPc showed significant negative correlations with the GII and some of its components, such as MMR and ABR, and also had significant negative correlations with the differences found in secondary education (DIFPSE), labour participation rates (DIFLFPR), the birth rate, the global fertility rate and the infant mortality rate. GDPc showed positive correlations with female parliament representation (SSPF), secondary education (PSEF) and labour participation (LFPRF). The infant mortality rate showed similar patterns, as it was positively correlated with GII and some of its components, such as the maternal mortality rate, adolescent birth rate and DIFPSE and DIFLFP, which also showed positive correlations with the birth rate and global fertility rate. The previously stated patterns could suggest a closer relationship between gender equality and child health indicators in Chile with GDPc, but not with height, which has been observed in other studies (Bozzoli et al., 2007; Mark, 2014; Silventoinen, 2003). Both the infant mortality rate and GDPc experienced significant improvements in Chile. In fact, the GDPc increase has led to Chile recently being labelled as a high-income economy by the World Bank (WorldBank, 2018). The infant mortality rate has decreased dramatically since 1955 from 120.3 to 11.5 (DEIS-MINSAL, 2019b) in 1995, while GDPc has increased from 669.6 USD in 1962 to 5137.3 USD in 1995 (WorldBank, 2018b). In the case of Chile, the infant mortality rate has been mainly reduced through efforts focusing on perinatal-health free services for women bearing children and supplementary food and milk programmes directed at women and children, even during the 1973-1989 period when democracy was interrupted (Borrescio-Higa et al., 2018). These state-wide efforts, mainly focused on women and their relationship with their offspring, probably translated into a reduction in gender inequalities, especially by providing bearing mothers with free high-quality healthcare and nutrition, which have been pinpointed together with education as fundamental pillars of gender equality (UNICEF, 2017), thus possibly explaining why the maternal mortality rate, adolescent birth rate, birth rate and global fertility rate were more strongly related than GDPc to height dimorphism.

6.4.6. Chile: height and gender equality overview

Chile has experienced great improvements in gender equality: it was ranked number 54 of 159 countries in 2018 in terms of the Global Gender Gap and reportedly closed 72% of its gender gap (WEF, 2018). Despite that progress, significant gender inequalities still persist in Chile, especially regarding paid employment (ComunidadMujer, 2018; WEF, 2018). Women face several challenges from when they are young girls that the boys of the same age do not. This is mainly due to cultural norms that discriminate or clearly harm girls. For example, female infanticide and preference for males in terms of food and medical care have resulted in 50 million females being absent from India alone (Mark, 2014), while other practices such as genital mutilation or child marriage focus on girls (UNHRC, 2011; Mark, 2014; UNICEF, 2016, 2017). Luckily, these practices are not the reality in Chile, but discriminatory practices and education have been present, since it was common for females born before the 1960's not to finish secondary education or to have to ask permission to attend university—it was assumed that they would be housewives and be financially supported by a husband, hindering any chance of development and independence (ComunidadMujer, 2018). Currently, women in Chile have higher labour participation rates than ever before and have actually surpassed male participation in higher education. However, they still perform the majority of the housework and study service-related careers and are still under-represented in engineering and science degrees (Arzola, 2011; Álvarez, 2015; ComunidadMujer, 2018). The relationship between mothers and their children, together with nutrition and health, has a relevant impact on overall well-being, whereby mothers who have a stronger bond with their children tend to have healthier outcomes and taller children (Cole, 2000). Similarly, increases in mother's height have been associated with a lower risk of poor child health (Bhalotra & Rawlings, 2011). Deaton (2009) has found that in India, where gender inequality has significantly higher indicators, height dimorphism has increased in some cohorts, attributing the finding to "a differential access to whatever improvements there have been in health or food or both". Other authors have found a positive secular trend in Indian girls' height, most likely stemming from improvements in living conditions such as nutrition and access to healthcare among women and girls (Agarwal et al., 1992). Therefore, it is possible that higher height dimorphism in the older cohorts of the current study is related to gender inequalities, since it has been observed that differential access to education, health and other welfare benefits can lead to height variations within the same group, especially in developing countries (Som et al., 2014) such as Chile in the years before 1990. Africa is the one exception: despite the poverty and adverse situation of women, they are actually taller than older cohorts; however, this has been attributed to a likely mortality selection favouring taller women (Deaton, 2007). In the current study, the birth year was considered the criterion for analysing the data since growth is considered cumulative during the first 2 years of an individual's life; therefore, the birth year can be considered a proxy for a starting point in height gain (Tanner, 1986, 1992; Cole, 2000, 2003;).

As shown in Figure 6.1, the GII shows a clear trend of gender inequality reduction in Chile; therefore, it would be interesting to compare height dimorphism using data from Chileans exposed to higher gender equality. In 2018, empowered by the #metoo movement, Chile experienced massive social movements demanding more gender equality policies, especially in education and work dimensions (Ruiz & Miranda, 2018; Salvo, 2018). Further research could examine height dimorphism, especially in cohorts born after 2011, when government funded paid maternal leave for all employed women.

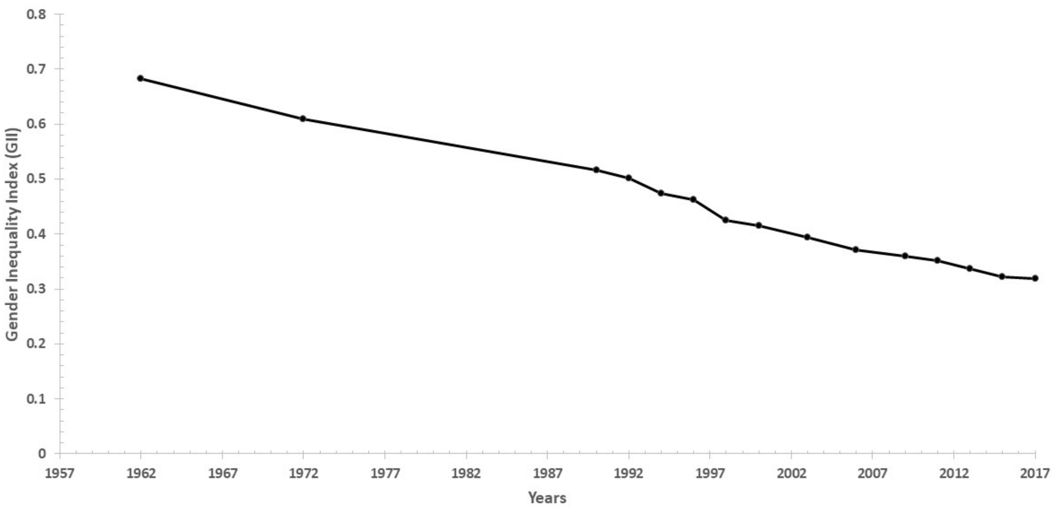

Figure 6.1. Gender Inequality Index (1962-2017)

6.4.7. Limitations

Limitations of the current study include the lack of basic historical information regarding female data. It is worth remembering that Chile was under a military regime from 1973-1989; therefore, some indicators prior to 1989 were not available (Ruiz & Boccardo, 2014). Even during democratic periods, information was not available, showing that historically Chile did not address females and demographics across the full spectrum, similar to what has been found by Koepke et al. (2018). The unavailability of raw data did not allow to perform a more in-depth causal analysis, however the averages used that apparently show a small sample, each of the data points used corresponded to 3.076 observations. Since correlation models were used, causation cannot be attributed to a particular variable; however, the relationships and historical data collected suggest that the relationship is highly probable. On the other hand, the strength of the current study is its use of directly measured dimensions by trained health professionals following standardized protocol that ensures a high quality of the data used and that is also more reliable than self-reported measures (Viviani et al., 2018).

6.5. Conclusion

Gender equality has improved significantly in Chile, even though some gender differences are still present. The current study found a reduction in the gap between female and male heights that is correlated with a reduction in gender inequality. Women's reproductive health indicators, education and child mortality rate are correlated with sexual dimorphism. GDPc did not show significant differences. Generally, variation in mean height is a proxy for changing environmental conditions affecting growth and, therefore, final height attainment. Accordingly, it seems that sexual height dimorphism can be used to complement the assessment of gender equality in a way that some global indicator well-being indicators may not consider, highlighting more clearly gender inequalities (Uvin, 1999; Koepke et al.,2018)

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CHAPTER 7| Application of mismatch equations to dynamic office seating designs

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Anthropometry is critical for product and working places design. Office work is highly prevalent and associated with sedentarism and physical discomfort, mainly through prolonged sitting. Dynamic seating (alternating between, sitting, perching and standing) has been suggested as an alternative to overcome the problems caused by prolonged sitting. The aim of the current study was to use a large sample of anthropometric data and test it for mismatch levels against a national and international office furniture standard using the dynamic seating as a framework, through traditional and perching mismatch equations, applied to the three recommended dynamic seating components. Dimensions present in the standards used did not match the majority of the sample. For sitting, seat width and depth, when analysed alone, were the dimensions that presented the lowest levels of match, while cumulative fit considering all the office furniture dimensions, showed lower levels of match, which increased when using adjustability. Perching presented a challenge, mainly because of the height limitation seen in chair height options. Current equations for perching are discussed and two new alternatives are presented that were used to propose design alternatives. Further research should focus on testing the criteria presented on this research for discomfort and objective measures.

Keywords: perching, sitting, posture, comfort, office.

7.1. Introduction

Anthropometric dimensions have been used in order to design products and working spaces on highly heterogeneous settings and users, from fire fighters (Hsiao et al., 2014; Hsiao, Whitestone, Kau, & Hildreth, 2015; Mcquerry, 2017) to highly specific sport equipment for people with disabilities (Bragança et al., 2018). Many ergonomic standards have been available since the 70`s and despite many unsolved ergonomics issues are still present today, there is more consensus on basic product design and user interface principles than ever before (Woo, White, & Lai, 2016). Overall, every design should be focused in achieving and optimum match for end users, which besides making products and workspaces safer and to perform better (Pheasant & Haslegrave, 2006), contribute to overall sustainability (Nadadur & Parkinson, 2013).

Since the massification of technology, physical work has been replaced gradually for more sedentary work, which has been associated with a greater postural and cardiovascular risk (Brownson, Boehmer, & Luke, 2005; Parry & Straker, 2013; Sowah et al., 2018). Office work is very common nowadays, contributing together with modern lifestyle, to the problems often seen in sedentary persons, were spending large portions of the day sitting have been associated to increased cardiovascular ill-health and musculoskeletal disorders, specifically low back pain (LBP) (Corlett, 2008; Kirk & Rhodes, 2011; Parry & Straker, 2013). Additionally, those workers with chronic LBP demonstrated a possible trend towards more static sitting behaviour compared to their pain-free counterparts (Bontrup et al., 2019).

Considering the previous information the interventions in office settings aim to either the individual (i.e. incidental walking promotion), the organization (policies for encouraging to move more) and the physical workplace (i.e. treadmill desks, sit to stand work stations, etc.) mainly aiming to increase movement and posture alternation while working (Parry, Coenen, O'Sullivan, Maher, & Straker, 2017).

"Proper" sitting posture is essential for preventing low back pain. Based on the conventional seating model, a standard office chair generally encourages an upright sitting posture, maintaining right angles at the ankles, knees, hips and elbows, however, working in the same posture or sitting still for prolonged periods may not be healthy nor feasible (Woo et al., 2016). Furthermore, Zemp et al., (2016) indicated that subjects who registered acute low back pain showed a clear trend towards a more static sitting behaviour.

The traditional sitting posture is based on the posture proposed by the German Doctor Staffel at the end of the 19th century, where hip, knee and ankle joints must maintain an angle of 90°, also known as cubist approach (Dainoff, Balliet, & Goernert, 1994). This posture can generate several problems, such as: tilting the pelvis backwards (retroversion) and rectification of the lumbar spine (Keegan, 1953); increase in intradiscal pressure at the spine's lumbar level (Andersson, Ortengren, Nachemson, & Elfstrom, 1974) ; overall decreased of the movement capacity of the spine and reduced circulation in the legs due to lack of muscular activity (Stranden, 2000), just to mention a few. In that regard, other alternative seating postures, as proposed by Mandal (1982), could be friendlier with the spine`s biomechanics, seeking an angle close to 130° between the thighs and trunk without losing verticality, also known as astronaut posture or perching. This position presents several advantages compared against Staffel's, such as: tilting the pelvis forwards (anteversion), thus maintaining the lumbar lordosis and decreasing intradiscal pressure (Noro, Naruse, Lueder, Nao-i, & Kozawa, 2012). Common approaches to obtain these benefits while sitting, have been either using higher chairs with forward slopes, saddle chairs and adjustable height desks to increase posture alternation and movement (Chambers, Robertson, & Baker, 2019; Johnston et al., 2019; Kuster, Bauer, Gossweiler, & Baumgartner, 2018; A. Mandal, 1991; Noguchi, Glinka, Mayberry, Noguchi, & Callaghan, 2019; Roossien et al., 2017; Vaucher et al., 2015). The benefits of these approaches have been observed in different populations, from dentist (Gouvêa et al., 2018) to school children (Castellucci, Arezes, Molenbroek, de Bruin, & Viviani, 2016). These and other interventions use furniture and equipment that allow users to modify their sitting posture according to their preference, work related use and comfort, thus hybrid sitting has been proven to be effective above from one or other specific posture (Noguchi et al., 2019).

Generally speaking, design equations do not take into account the previous concepts, since they are very difficult to implement in standards aimed for fit larger populations (Dainoff et al., 1994). In terms of accommodating larger populations, the commonly seen paths are either generating stratified fixed designs or using adjustability (Underwood & Sims, 2019). Even if adjustable designs are used, there are always economic constraints associated with them, increasing production and final costs, which can jeopardize product viability, while on the other hand accommodating less than 90% of the population can cause issues on its own, compromising product sustainability and user safety (Nadadur & Parkinson, 2013; Pheasant & Haslegrave, 2006).

The aim of the current paper is to apply different design equations using a recent anthropometric database of Chilean workers in order to test the level of mismatch of available standards and products for three common sitting designs: a) traditional seating with fixed desk and adjustable chair, b) traditional seating with adjustable chair and desk, c) hybrid seating with adjustable chair and desk.

7.2. Materials and Methods

7.2.1. Sample

During 2016, anthropometric dimensions were collected by the authors of this article as a part of a larger research project, ending up with 32 anthropometrics measures. Data were collected on 2,946 workers (600 female and 2,346 male) from the two most populated regions of Chile (Valparaíso and Metropolitana) distributed by 9 economic activity sectors (Agriculture and fishing; Mining; Manufacturing; Electricity; Construction; Commerce; Transport and communications; Financial services; and Communal and personal services).

Measurements were collected manually by specialized teams of physiotherapists who underwent training and performed pilot studies to assess both inter- and intra-measurer reliability, in order to obtain high quality measurements (Viviani et al., 2018). The full sample and more details about the procedure can be seen in a recent publication (Castellucci et al., 2019).

7.2.2. Anthropometric dimensions

The dimensions used can be seen in Table 7.1. They were the most commonly used dimensions to design for sitting postures (Castellucci, Arezes, & Viviani, 2010; Pheasant & Steenbekkers, 2005).

Table 7.1. Anthropometric dimensions used

Anthropometric measurements	Definition
Shoulder height standing (SHstand)	vertical distance from the floor to the acromion.
Elbow height standing (EHstand)	taken with a 90° angle elbow flexion. as the vertical distance from the bottom of the tip of the elbow (olecranon) to the floor.
Shoulder height sitting (SHsit)	vertical distance from subject's seated surface to the acromion.
Elbow height sitting (EHsit)	taken with a 90° angle elbow flexion. as the vertical distance from the bottom of the tip of the elbow (olecranon) to the subject's seated surface.
Abdominal depth (AD)	maximum horizontal distance from the vertical reference plane to the front of the abdomen in the standard sitting position.
Thigh thickness (TT)	vertical distance from the highest uncompressed point of thigh to the subject's seated surface.
Buttock-Popliteal Length (BPL)	horizontal distance from the popliteal surface to the rearmost point of the buttock.
Popliteal height (PH)	vertical distance from the floor or footrest and the posterior surface of the knee (popliteal surface).
Hip width (HW)	horizontal distance measured in the widest point of the hip in the sitting position
Foot length (FL)	maximum distance from rear of the heel to tip of the longest (first or second) toe, measured parallel to the longitudinal axis of the foot.

7.2.3. Furniture dimensions

Furniture dimensions considered in the following research were: Seat Height, Seat Width, Seat Depth, Seat to Desk Clearance (SH adjustable and DH fixed), Seat to Desk Clearance (fully adjustable), Legroom Depth, Desk height (adjustable) and Desk height (fixed). These dimensions can be better seen in Figure 7.1 and presented in table 7.2.

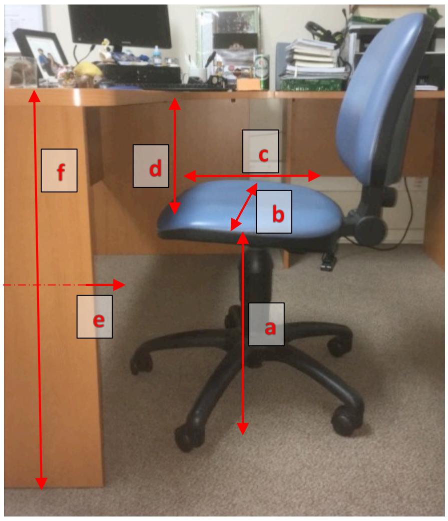


Figure 7.1. Office furniture dimensions used. a) seat height b) seat width c) seat depth d) seat to desk clearance e) legroom depth f) desk height

7.2.4. Procedure

As described in the introduction, three scenarios were tested using the available anthropometric data. Each one is addressed in a separate sub section of this paper. All of the alternatives were compared with criteria present in Chilean recommendation (ISP, 2016) and European standards (CEN, 2000, 2011). In all of the mismatch equations were heights are involved, a shoe correction factor (SC) is included of 2,5 cm (25 mm) since all measurements were taken barefoot as stablished on the respective ISO standard (ISO, 2008).

The dimensions of these standards can be seen in table 7.2. On each situation a level of accommodation of 90% will be considered as acceptable (Pheasant & Haslegrave, 2006). Note from table 7.2 that Seat to Desk Clearance (SDC) has a combination of adjustable seat height (SH) with fixed (DHf) or adjustable desk height (DHa).

Table 7.2. European (CEN) and Chilean (ISP) recommended office furniture dimensions

Furniture dimension	ISP (in mm)	CEN (in mm)
Seat Height (SH)	350-500	400-510
Seat Width (SW)	460	400
Seat Depth (SD)	400	400-420
*Seat to Desk Clearance (SDC)	200-350	180-290
^ Seat to Desk Clearance fully adjustable (SDCa)	50-350	90-400
Legroom Depth (LD)	790	800
Desk height adjustable (DHa)	600-750	650-850
Desk height fixed (DHf)	750	740

* SH adjustable and DH fixed; ^ both SH and DH adjustable; note: Desk top thickness 50 mm

Anthropometric dimensions were tested against office furniture dimensions present in Table 7.2, where both single measure match and cumulative fit were done. It is important to considerer the cumulative fit or transversal mismatch, which is defined as the mismatch that takes into account the cumulative values of the different furniture dimensions (Castellucci, Arezes, & Molenbroek, 2014). This can be considered as a very important indicator of the furniture fit, since it shows how many workers are actually matched to the dimensions of the furniture. The order to apply the cumulative fit was done using a bottom to top approach, meaning that starting from the base (feet flat on the ground) to consider the cumulative fit or transversal mismatch (Castellucci et al., 2014). Some of the equations described in the following sections are two-way, i.e. both the minimum and maximum limits were considered. In these cases, three categories were used for the classification of the levels of match: (1) "Match" level, when the furniture dimensions are between the minimum and maximum limits; (2) "High mismatch" level, when the maximum limit of the equation is lower than the furniture dimension, indicating that the furniture dimension is higher than needed; and, (3) "Low mismatch" level, when the minimum limit of the equation is higher than the furniture dimension – in this case, the furniture dimensions are lower than the recommended level (Castellucci et al., 2016).

7.2.4.1. Traditional seating with adjustable chair and fixed desk

There are several studies about equations in the literature, such as the one developed by Castellucci et al. (2015). Table 7.3 shows the different mismatch equations used. The testing has the following order: SH, SW, SD, SDC, LD and DH. It is important to highlight that LD equation was developed by the researchers, where further explanations and rationale can be seen in the Theory/calculation section.

Table 7.3. Match equation for traditional office furniture

Furniture dimension	Mismatch equation
SH	(PH + SC) cos30° ≤ SH ≤ (PH + SC) cos5°
SW	HW < SW
SD	0.80BPL ≤ SD ≤ 0.95BPL
SDC	TT + 2 < SDC
LD	(BPL + PH sin30° + FL) – AD
DH	(PH + SC) cos30° + EHSit≤ DH ≤ (PH + SC) cos5° + EHSit*0.8517+ SHSit*0.1483

SH: seat height; SW: seat width; SD: seat depth; SDC: Seat to Desk Clearance; LD: leg room depth; DH: desk height; PH: popliteal height, SC: shoe correction; HW: Hip width; BPL: buttock-popliteal length; TT: thigh thickness; FL: foot length; AD: abdominal depth, EHsit: elbow height sitting; SHSit: shoulder height sitting.

7.2.4.2. Traditional seating with both adjustable chair and height desk

The application of the level of mismatch with this setup was performed using the same equations than in the previous application (Table 7.3), being the only difference that minimum and maximum ranges for chair and height desk (adjustability ranges), which aim to include most of the population (at least 90%).

7.2.4.3. Hybrid seating (sitting, perching and standing) using adjustable height chair and desk

During this part of the analysis only heights will be addressed. Depths and widths will be excluded since they were already checked for mismatch in sections 7.2.4.1 and 7.2.4.2 therefore the same criteria in Table 7.3 were applied. For assessing the match of the heights, a bivariate approach was used, since two/multiple anthropometric dimensions are relevant to the function of the product (Dianat, Molenbroek, & Castellucci, 2018).

Heights, and SH in particular, are the most important measure for mismatch criteria and therefore is the focus of this section (Castellucci et al., 2016). A bottom-top approach was used, where the testing has the following order: SH and DH. During this set up the authors tried to test if a single design could match the sample when sitting, perching and standing. Dimensions for two frequently used adjustable chair configurations, namely saddle chairs Capisco (by HAG®) and Balance (by Score Amazone®) were used. Additionally, the dimensions of the commercially available adjustable height desk (E-model®) and the (CEN, 2000, 2011) recommendation were used.

Seat to Desk clearance was not tested since full adjustability allow users to readily obtain it, since the bottom to top approach is used thigh space needs to be always present, otherwise the person will not be able to sit, thus being desk height adjustable it does not present problem. Details on this application will be discussed in the Theory/calculation section.

7.3. Theory/Calculation

It has been reported that the "upright posture" (hips, knees and ankles at right angles) heavily recommended on the ergonomics field have several issues. For example this "upright posture" cannot be sustained more than 1-2 minutes (Mandal, 1981) and additionally, this posture can cause biomechanical problems since in an upright seated person the lumbar curve changes from a lordosis (standing position) to an kyphosis (sitting position) (Mandal, 1994a; Zacharkow, 1987). This is also supported by the work of (Schoberth cited by Mandal 1981), who found from X-ray examinations of 25 people sitting upright, an average 60° hip flexion and 30° lumbar flexion. Time spent added to poor postures can significantly increase low back issues on seated workers (Bendix, 1994), especially considering current sedentary jobs that require to be seated for long periods of time (Coenen, Gilson, Healy, Dunstan, & Straker, 2017).

The featured principles regarding design need to enforce the changes of postures , also known as Dynamic Sitting, from sit to stand and through half-standing positions, also known as semi sitting or perching (Bendix & Bridger, 2004). Several principles have been documented that need to be addressed in order to be able to sit dynamically. Firstly, the desk should be adjustable in height coupled with a high saddle chair or tilting seat pan (Fettweis et al., 2017; Mandal, 1994a); however, in both cases feet must be on the floor. Mandal (1994a) has reported a reduction in lumbar flexion and pain plus more preferences by users with office furniture higher than the ones proposed by the standards.

Additionally, the positive seat angle (or the forward sloping seat) is based on the principles that most work activities require a forward leaning posture, without any use of the backrest (Lueder & Berg Rice, 2008). Furthermore, the backrest or lumbar support will only have a beneficial effect if the chair presents a negative seat or a backwards sloping seat (Mandal 1994). Mandal (1982)also argued that the need for lumbar support is one of the four fallacious design principles of sitting, since users often prefer seats that allow seated postures with less flexion of the spine at the expense of higher seats, with either tilting seat pans or saddle chairs, and higher desks (Mandal, 1994a). The rationale of having a backrest is that the lumbar support keeps the lordosis while seated, however it is not always the case (Bendix, 1994), since users in practice tend to lean forward and not using it at all (Bendix & Bridger, 2004), especially when seating in higher office furniture with greater trunk/thigh angles (Mandal 1994). However, the backrest should be present since it allows users to lean back and adopt an additional posture, thus contributing to dynamic seating (Bendix, 1994). Mandal (1994) suggested the use of higher furniture, seat height should be between 2-4 cm higher than PH. This presents a challenge for design in two main aspects. Firstly, 2 to 4 cm, is proportionally very different for people with different dimensions of PH. Secondly, perching is not addressed often in standards.

Figure 7.2a shows the traditional or conventional seating, for which mismatch equations can be found in several standards and publications (Castellucci et al., 2015), however perching design guidelines are hard to find (Dainoff et al., 1994). In that regard, it can be considered for someone to be perching when at least a trunk/thigh angles of 105° is obtained (Figure 6.2b), which automatically place the pelvis and lumbar spine in a neutral position (Bendix & Bridger, 2004). Other authors have found that ideal trunk/thigh angles of 120° (Figure 6.2c) (Mandal, 1991; Noro, Naruse, Lueder, Nao-i, & Kozawa, 2012) while others consider that ideal perching trunk/thigh angle starts at 135° (Figure 6.2d)(Keegan, 1953; A. C. Mandal, 1981; Noguchi et al., 2019; Rohlmann, Zander, Graichen, Dreischarf, & Bergmann, 2011)

The current research will therefore address in a novel manner two essential components of dynamic seating, namely: standing (Figure 7.2e) and perching. In the following sections equation for calculating traditional seating, perching and standing will be discussed.

7.3.1. SH equation

Regarding SH, different equations can be used, depending on the desired posture that is aimed for users to adopt. In the current research, SH can be either calculated by considering traditional sitting only and sitting plus perching.

7.3.1.1. Traditional or conventional sitting

In order to determine SH for traditional or conventional sitting the following equation was used:

$$(PH + SC)\cos 30° \leq SH \leq (PH + SC)\cos 5°$$

This equation has been widely used for estimating mismatch for traditional sitting (Afzan et al., 2012; Agha, 2010; H. I. Castellucci et al., 2014; Dianat, Karimi, Asl Hashemi, & Bahrampour, 2013; Gouvali & Boudolos, 2006).

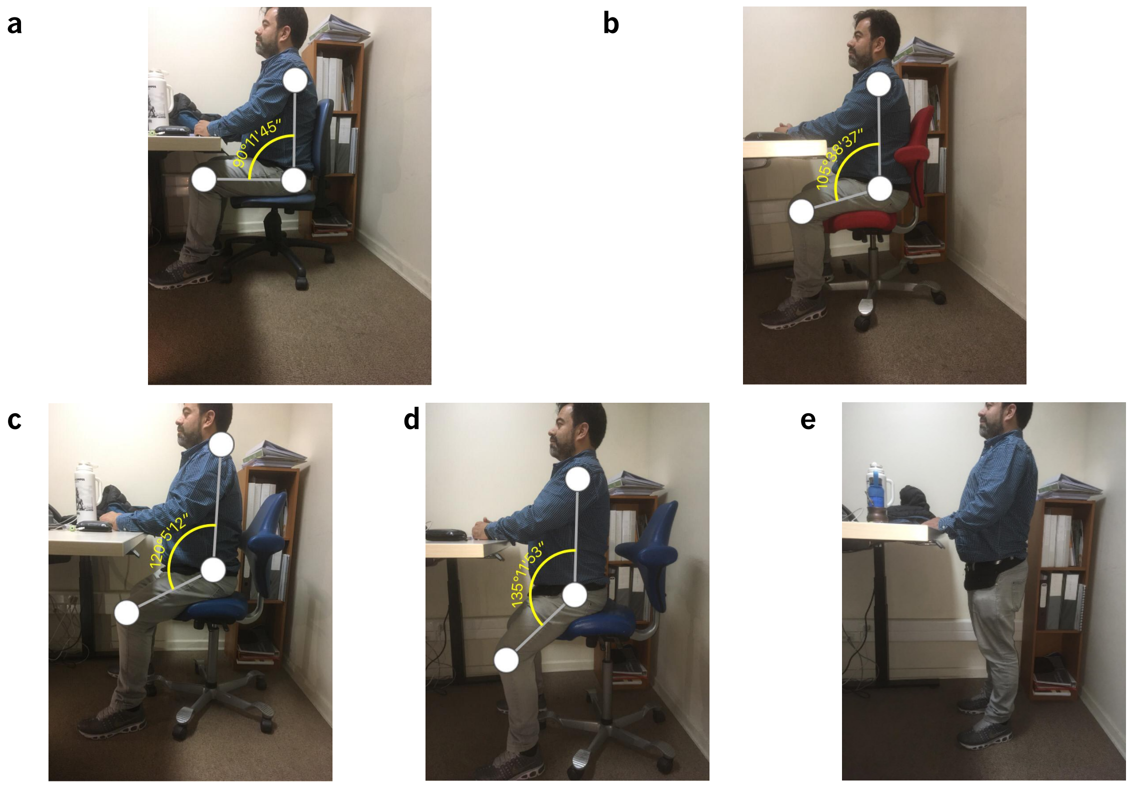


Figure 7. 2. Hybrid Sitting Postures. a) Traditional sitting with 90° trunk/thigh angle b) perching with 105° trunk/thigh angle c) perching with 120° trunk/thigh angle d) perching with 135° trunk/thigh angle e) standing

7.3.1.2. Perching

As mentioned previously, the height increases of the furniture and considering perching angles between 120°-135° are suggested. In that regard, perching could be obtained either with a taller seat with a forward slope or with a saddle chair. The CEN standard for school furniture is the only one that uses perching (CEN, 2015). The equation used by CEN, (2015) can be seen below:

CEN equation: SH (conventional sitting) + SD x 2Tanα (α=15°).

The equation used by CEN (2015) aims for users to attain a 120° trunk/thigh angles, since two rationales were used. First, the standard is based on scalability and not adjustability, thus they used seat depth dimensions as a base to calculate the seat height increase. Second, since it considers traditional seating, thus a 90° trunk/thigh angle added to an additional 30° obtained by adding up the resultant vertical height of two times Tanα. For example, figure 6.3a shows the rationale of the CEN (2015) equation, were heights "a" and "b" are equal and obtained by the function described previously. Height "c" is obtained from conventional seating. Thus, final seat height is obtained adding heights a, b and c. Notice from figure 7.3a, that in practice, the seat it is not forward sloped by 30°, only 15°, otherwise the weight will be transferred to the feet through a "sliding" effect, thus increasing lower limb demands (Noguchi et al., 2019).

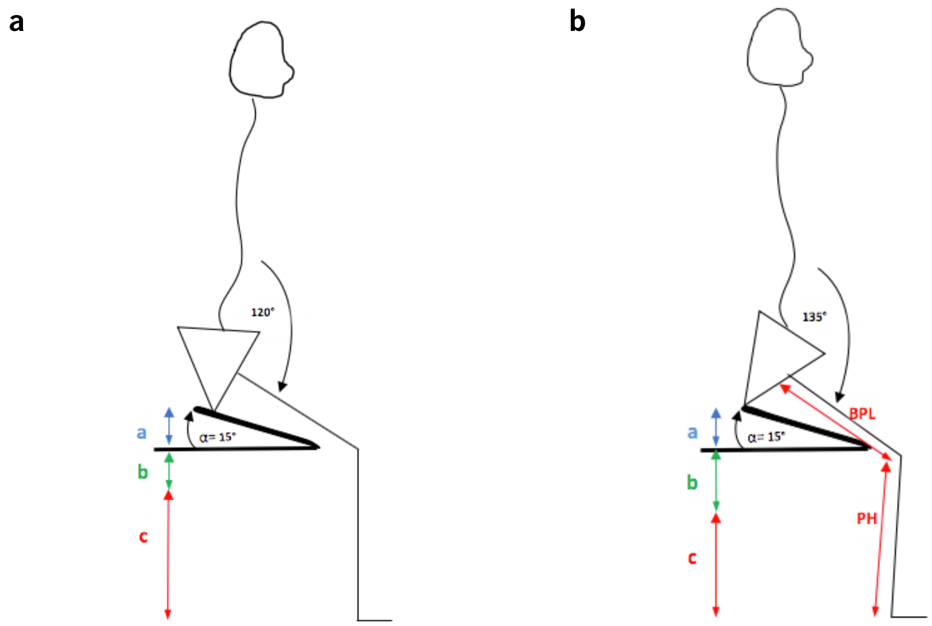


Figure 7.3. Rationale for perching posture through slope and height. a) CEN (2015) standard rationale b) proposed forward slope alternative. PH: Popliteal height. BPL: Buttock Popliteal Height

Additionally, designers and human factor specialists could choose to facilitate perching with a higher angle, namely 135° by the means of a forward slope**.** If slope alone was the only way for a forward slope chair to achieve perching at a 135° thigh-trunk angle, it will be too high (45°) and result in sliding of the buttocks forward and translating all of the weight to the feet therefore a maximum forward slope angle of 15° is recommended (E. Corlett & Gregg, 1994). For that purpose, the following equation could be used:

Forward slope (15°) equation: ((PH+2.5) * cos5° + BPL * sin30°) + (BPL * sin15°)

Observing figure 7.3b note that for achieving the 135° perching with a forward slope of 15°, the remaining 30° of slope are achieved by increasing the chair height as shown in Figure 6.3b. This is reflected in the first part of the equation and calculated with a combination of the vertical distances obtained through basic trigonometry, using Buttock Popliteal Length (BPL*sin30°), represented by height "b" in green, and Popliteal Height (PH * cos5°) represented by height "c" in red plus a shoe correction of 2.5 cm. The latter part of the equation "completes" the chair height through a 15° slope using BPL (height "a" in blue) Both equations consider the fact that when forward slopes are used the user mainly seats in the front part of the seat, with no need to use the backrest and carrying more weight on the feet (Mandal, 1991, 1994a, 1994b), therefore BPL length is not used as in traditional seating equation.

The equation proposed and used in the current research for perching, uses a mix between the increased angle through the use of a saddle chair and an increase in seat height, mainly based on adjustability. In our case, and since we use raw data and do not have a previously established seat depth dimension as CEN (2015), we considered the use of the BPL through the sin of 45° for 135° thigh-trunk angle. Also, the same equation could be applied for different trunk/thigh angle i.e.: 120° thigh-trunk angle replace by sin of 30° and for 105° thigh-trunk angle replace by sin of 15°.

Saddle chair equation: (PH+2.5) *cos5° + BPL * sin45°

This was done since it would be unwise not to consider BPL for designing seat height, since seat depth is affected by seat high increase, which is the case here, where final seat height for perching will be higher. In that case, the user will probably use the front part of the seat so, using BPL and not seat depth would be advisable. Figure 7.3 shows the rationale used, where if one would consider seat depth only (straight horizontal black line) it will not account for the actual orientation of BPL in space.

7.3.2. DH equation

DH was calculated in order to obtain a minimum and maximal height corresponding to the adjustability ranges. Equations use a combination of SH and DH since the desk should match users while sitting traditionally, perching and standing. Standing equations are based in the principles of Chaffin & Anderson (1991).

Low Limit (sitting): (PH + SC) cos30° + EHSit≤ DH ≤ (PH + SC) cos5° + EHSit*0.8517+ SHSit*0.1483

High Limit (standing): EHStanding ≤ DH ≤ EHStanding *0.8517+ SHStanding*0.1483

7.3.3. LD equation

When calculating LD for traditional or conventional seating, the following equation was described by Molenbroek et al., (2003):

LD Traditional equation: BPL+PH x sin30°+FL

The equation considers a LD were someone could extend their knees at least to 30°. An issue arising with the previous calculation is that it does not account for the situation were the abdomen is in contact with the edge of the desk.

Figure 7.4 shows how AD is introduced for overcoming the issue described above, therefore the equation used was:

Proposed equation for LD: (BPL + PH sin30° + FL) – AD

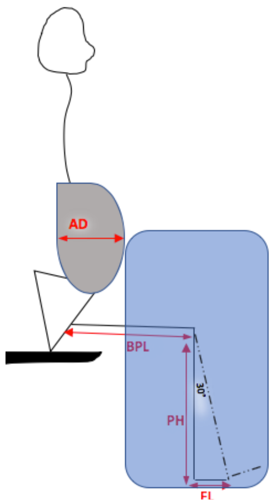


Figure 7.4. LD equation considering AD

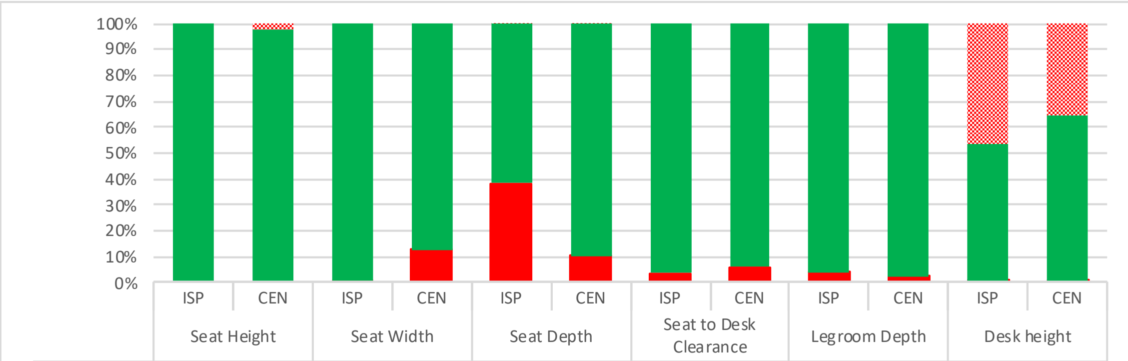
7.4. Results and Discussion

7.4.1. Traditional seating with adjustable chair and fixed desk

Figure 7.5a and 7.5b show the levels of mismatch by dimension and cumulative mismatch. Note that when considering individual dimensions, both Chilean (ISP, 2016) and European (CEN, 2000, 2011) standards have match percentages above 90% for the following dimensions: Seat height (ISP:100%, CEN:97,7%), Seat to desk Clearance (ISP:96,5%, CEN:93,9%) and Legroom Depth (ISP:95,8%, CEN:97,4%). The lowest level of match was observed in desk height for both standards, were in this case it had a mismatch of ISP:46,7%, CEN:35,6% (high mismatch), followed by seat depth with ISP:38,5%, CEN:10,5% mismatch (low mismatch). Seat width showed only a low mismatch for CEN standard (12,8%).

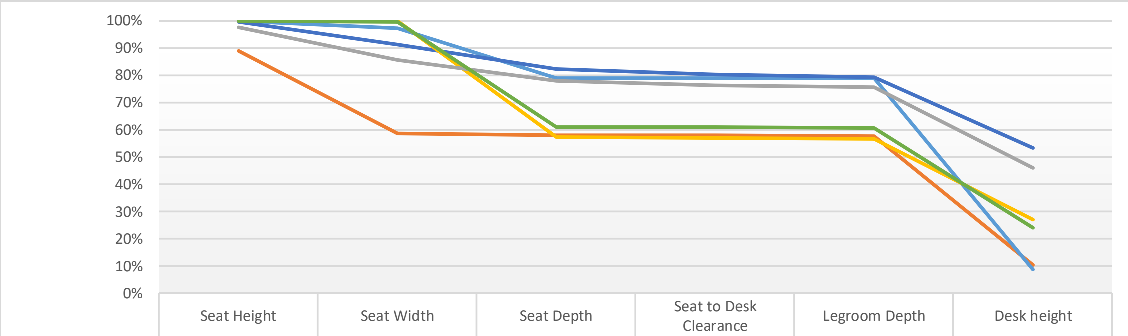
Note from Figure 7.5b, that total cumulative match, when considering basic office furniture dimensions for chair and desk, drop significantly in both standards (ISP: 24%, CEN: 46%). Note also that using the Chilean dimensions for traditional office furniture will result in only 24% of all users accommodated by the design. Note also that female population have the lowest levels of cumulative match (ISP: 9%, CEN: 10%) when compared to males (ISP: 27%, CEN: 53%). Note also that in almost all comparisons, CEN (2000, 2011) standard dimensions, even if still low, it increases by twofold the levels of match than using ISP (2016) dimensions, therefore it seems that the European standard may provide better match for Chilean users than the corresponding ISP national Standard. These results were expected since the lack of adjustability of the desk will reduce the % of users accommodated by the design (Underwood & Sims, 2019). In this case, it means that a single design will not be able to accommodate most users, thus the choices should be either to stratify and have more than one desk height or adding an adjustable desk. The latter situation will be analysed in the following section.

a



	Seat Height ISP	Seat Height CEN	Seat Width ISP	Seat Width CEN	Seat Depth ISP	Seat Depth CEN	Seat to Desk Clearance ISP	Seat to Desk Clearance CEN	Legroom Depth ISP	Legroom Depth CEN	Desk height ISP	Desk height CEN
H. Mismatch	0,0%	2,3%	0,0%	0,0%	0,2%	0,2%	0,0%	0,0%	0,0%	0,0%	46,7%	35,6%
Match	100,0%	97,7%	99,5%	87,2%	61,3%	89,3%	96,5%	93,9%	95,8%	97,4%	53,3%	64,3%
L. Mismatch	0,0%	0,0%	0,5%	12,8%	38,5%	10,5%	3,5%	6,1%	4,2%	2,6%	0,0%	0,1%

b



	Seat Height	Seat Width	Seat Depth	Seat to Desk Clearance	Legroom Depth	Desk height
Female CEN	89%	59%	58%	58%	58%	10%
Female ISP	100%	97%	79%	79%	79%	9%
Male CEN	99%	91%	82%	80%	79%	53%
Male ISP	100%	100%	57%	57%	57%	27%
TOTAL CEN	98%	86%	78%	76%	76%	46%
TOTAL ISP	100%	99%	61%	61%	61%	24%

Figure 7.5. Match % of traditional seating with fixed desk and adjustable chair match. a) Levels of match for individual measurements according to European (CEN, 2000, 2011) and Chilean (ISP, 2016) Office standards b) Cumulative mismatch with CEN and ISP standards per sex and entire sample

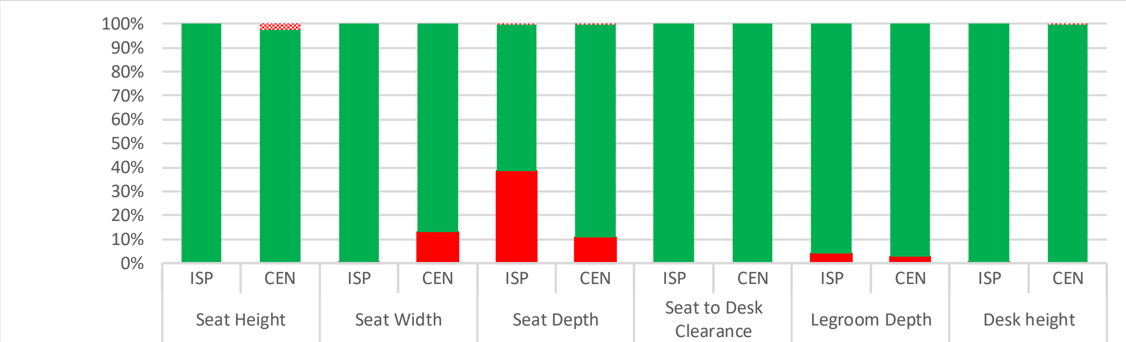
7.4.2. Traditional seating with both adjustable chair and height desk

Figure 7.6a and 7.6b. shows the levels of mismatch by dimension and cumulative mismatch. Note that when considering individual dimensions, both Chilean (ISP, 2016) and European (CEN, 2000, 2011) standards have match percentages above 90% for the following dimensions: Seat to desk Clearance (ISP:100%, CEN:100%) Seat height (ISP:100%, CEN:97,7%), Desk Height (ISP:99,9%, CEN:99,6%) and Legroom Depth (ISP:95,8%, CEN:97,4%).

The lowest level of match was observed in SD for both standards (ISP:61,3%, CEN:89,3%), followed by SW only for CEN with 87,2% match. In this application, SD will not be enough with none of the dimensions present in the standard.

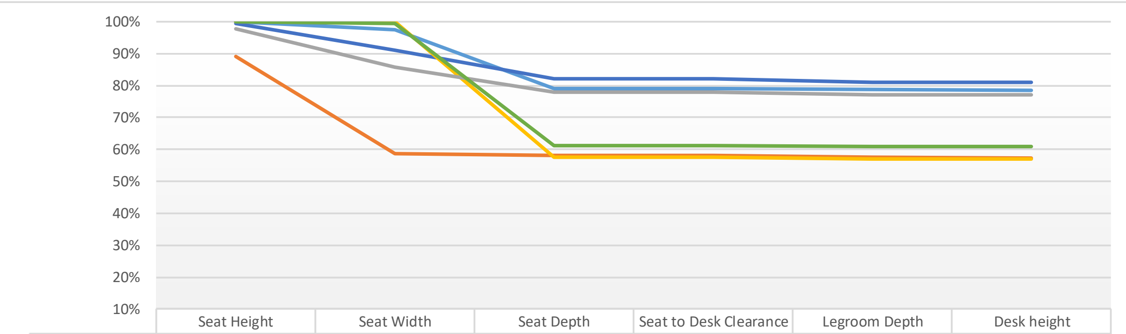
Regarding total cumulative match when considering adjustable height dimensions for both chair and desk and comparing to the previous setting (fixed desk), the values increased significantly by a 31% and 37% for CEN and ISP respectively. This is probably due to the addition of an adjustable desk; thus, mismatch is reduced. Despite that, it still showed a low percentage of match for both standards (ISP:61%, CEN:77%). The highest level of cumulative match was obtained when using the ISP dimensions in females (79%) and the CEN dimensions for males (81%). In general CEN dimensions are bigger than the ones propose by ISL standard, despite that, SW in that particular standard produced the lowest level of match, probably mediated by the secular trend experienced by Chilean population over the last two decades related to the increase in obesity (Kagawa, Fernald, & Behrman, 2016; MINSAL, 2011; Ratner, Sabal, Hernández, Romero, & Atalah, 2008; Salinas, Lera, González, Villalobos, & Vio, 2014; Vio, Albala, & Kain, 2010). This situations has been reported in SW by previous research (Molenbroek, Albin, & Vink, 2017).

a



	ISP Seat Height	CEN Seat Height	ISP Seat Width	CEN Seat Width	ISP Seat Depth	CEN Seat Depth	ISP Seat to Desk Clearance	CEN Seat to Desk Clearance	ISP Legroom Depth	CEN Legroom Depth	ISP Desk height	CEN Desk height
H. Mismatch	0,0%	2,3%	0,0%	0,0%	0,2%	0,2%	0,0%	0,0%	0,0%	0,0%	0,0%	0,4%
Match	100,0%	97,7%	99,5%	87,2%	61,3%	89,3%	100,0%	100,0%	95,8%	97,4%	99,9%	99,6%
L. Mismatch	0,0%	0,0%	0,5%	12,8%	38,5%	10,5%	0,0%	0,0%	4,2%	2,6%	0,0%	0,0%

b



	Seat Height	Seat Width	Seat Depth	Seat to Desk Clearance	Legroom Depth	Desk height
Female CEN	89%	59%	58%	58%	58%	57%
Female ISP	100%	97%	79%	79%	79%	79%
Male CEN	99%	91%	82%	82%	81%	81%
Male ISP	100%	100%	57%	57%	57%	57%
TOTAL CEN	98%	86%	78%	78%	77%	77%
TOTAL ISP	100%	99%	61%	61%	61%	61%

Figure 7.6. Match % of traditional seating with adjustable desk and adjustable chair. a) Levels of match for individual measurements according to European (CEN, 2000, 2011) and Chilean (ISP, 2016) Office standards b) Cumulative mismatch with CEN and ISP standards per sex and entire sample

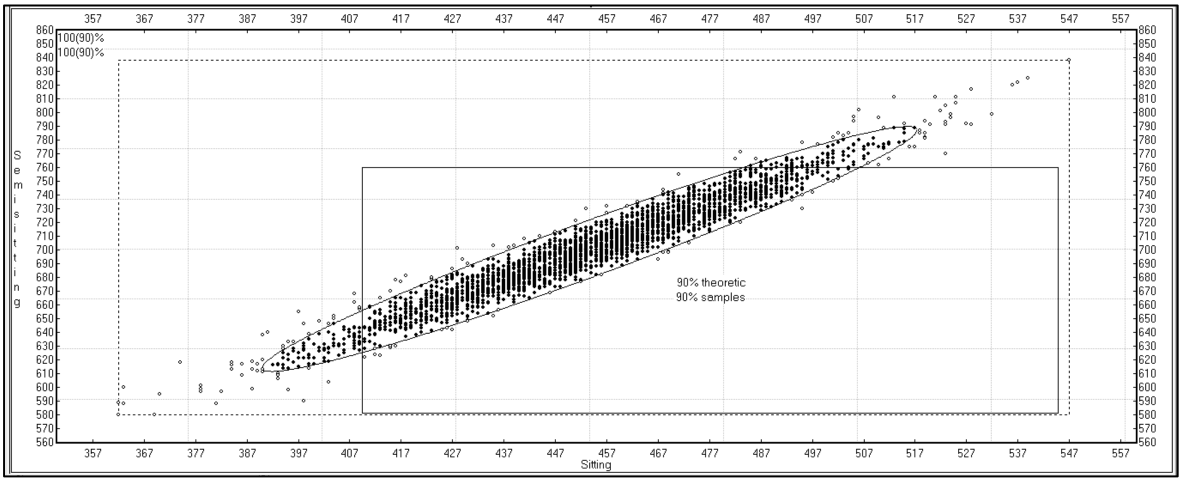
7.4.3. Hybrid seating (sitting, perching and standing) using adjustable height chair and desk

7.4.3.1. Hybrid seating adjustable height chair

The current research also tested the levels of match with a hybrid seating configuration. In order to covered 90% of the population by the design, SH range from 410 to 760 mm is needed, which will allow users to be seated, with a 90° thigh/trunk angle, using the 5th percentile of PH and perching with a thigh/trunk angle of 120° using the 95th percentile of PH (Figure 6.7a).

In Fig 7.7b the same analysis was carried out but with a perching trunk/thigh angle of 135°. In this case, the only way to increase the angle is to also increase SH, were users will have to seat in a chair starting from 410 to 870 mm. Similarly, to Fig 7.7a, 90% of the intended users will be accommodated by this configuration, however, this may provide an additional challenge due to the large range of the lifts that should be used in order to obtain the minimum and maximum values for the SH.

a



b

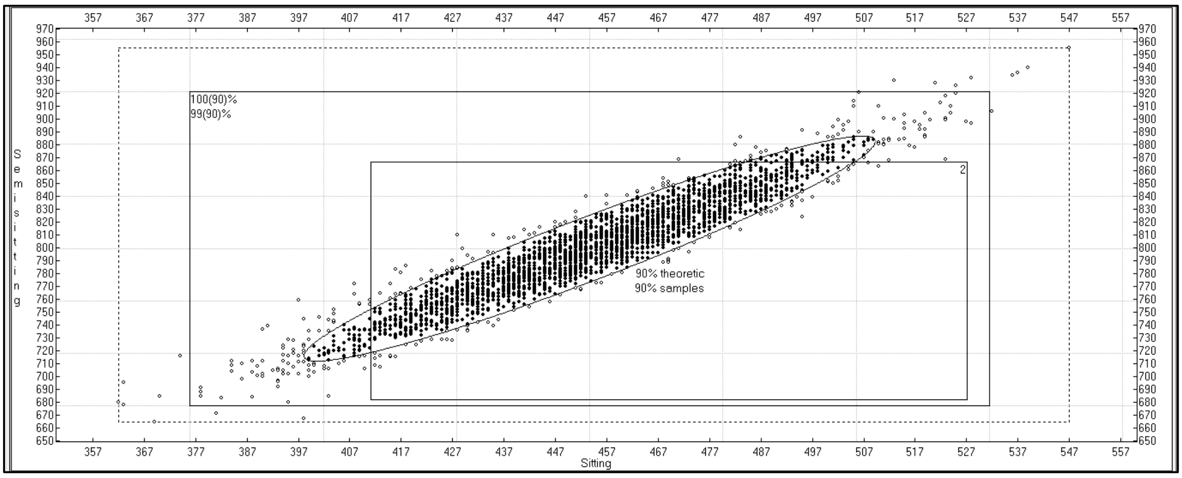


Figure 7.7. Levels of match in sitting and perching a. 90°-120° thigh/trunk angle; b. 90°-135° thigh/trunk angle

In figure 7.8, three configurations were tested in the sample using the HAG Capisco chair, with three lifts: small/blue (SH 400-650mm), medium/green (SH 480-660mm) and large/red (SH 580-830mm). In figure 7.8a three lifts were tested at a 90° and perching at 120° trunk/thigh angles. Note that in figure 7.8a only 6% will be accommodated with the small lift while 0% of the intended users will be accommodated by the medium lift and large lift values it is out of the boundaries of the figure. In figure 7.8b the large lift was used with a 105° trunk/thigh angle and perching 135° trunk/thigh angle. The use of 105° trunk/thigh angle instead of 90°, was because in order to attain the 135° trunk/thigh angle upper limit, the low limit needs to be greater, since with 90° trunk/thigh the level of mismatch was 100%. Note from Figure 7.8b that the level of match was 29% and none of the others two lifts can be draw since are out of the boundaries.

Finally, seated at 90° trunk/thigh angle and perching 135° trunk/thigh angle, figure 7.8c shows the results adding a footrest of 200mm recommended by the manufacturer. It is important to highlight that 78% of match is achieved with the large lift and none of the others two lifts can be draw since are out of the boundaries.

a

b

c

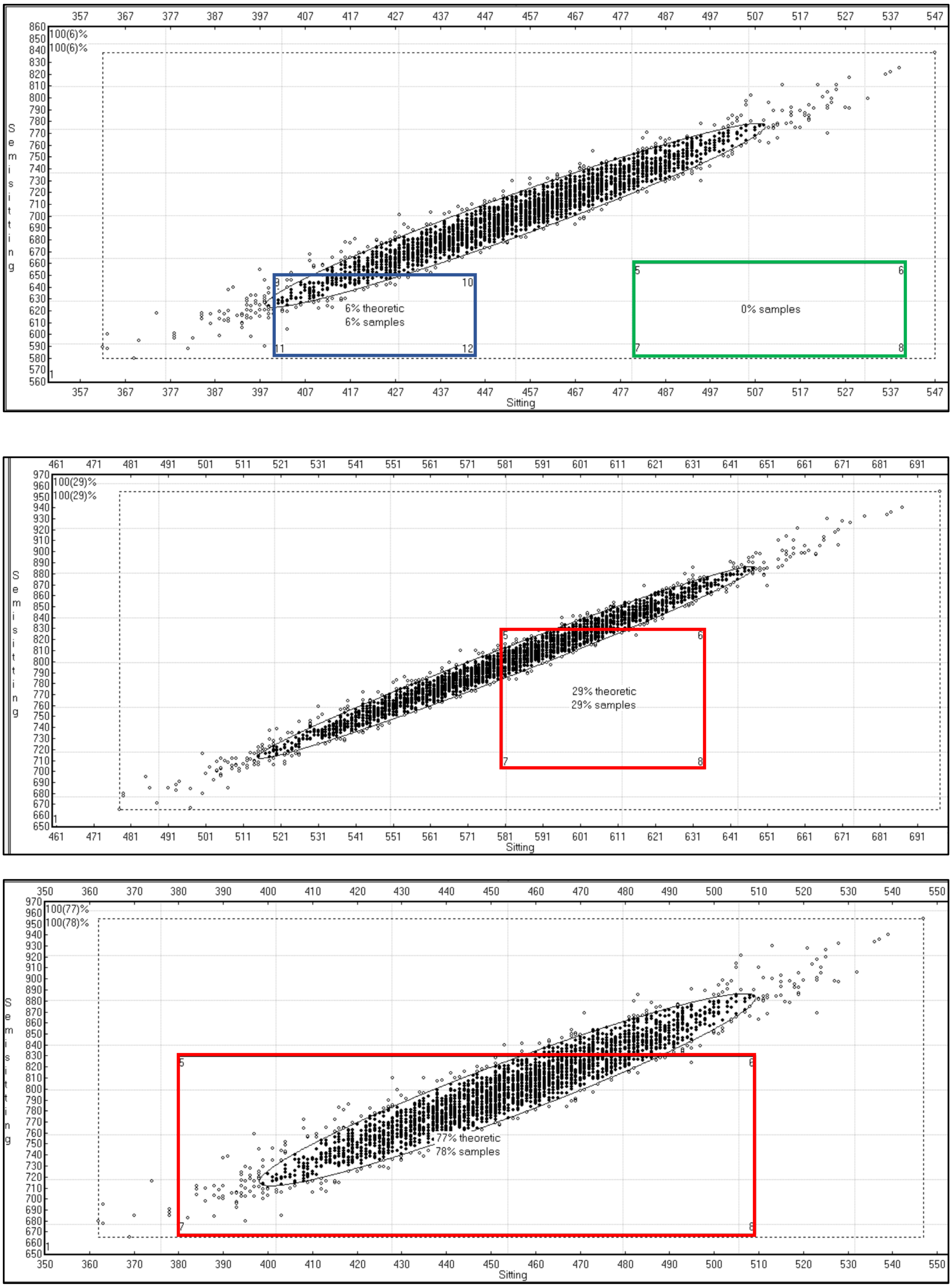


Figure 7.8. Levels of match using saddle chair for perching and sitting. a. sitting at a 90° and 120° trunk/thigh angle with small/blue and medium/green lifts; b. sitting at 105° and 135° trunk/thigh angle with large/red lift; c. sitting at 90° and 135° trunk/thigh angle with large/red lift plus 200mm footrest.

In figure 7.9 two configurations were tested in the sample the Amazone Balance chair with three lifts: small/blue (SH 490-630mm), medium/green (SH 570-760mm) and large/red (SH 630-880mm). In figure 7.9a the three lifts were tested at a 90° and perching at 120° trunk/thigh angles and they accommodate no one in the sample. Furthermore, the others two lifts cannot be draw since are out of the boundaries. In figure 7.9b, with seated at 105° trunk/thigh angle and perching 135° trunk/thigh angle, no one is accommodated by the medium lift and only 3 % is accommodated by the larger lift.

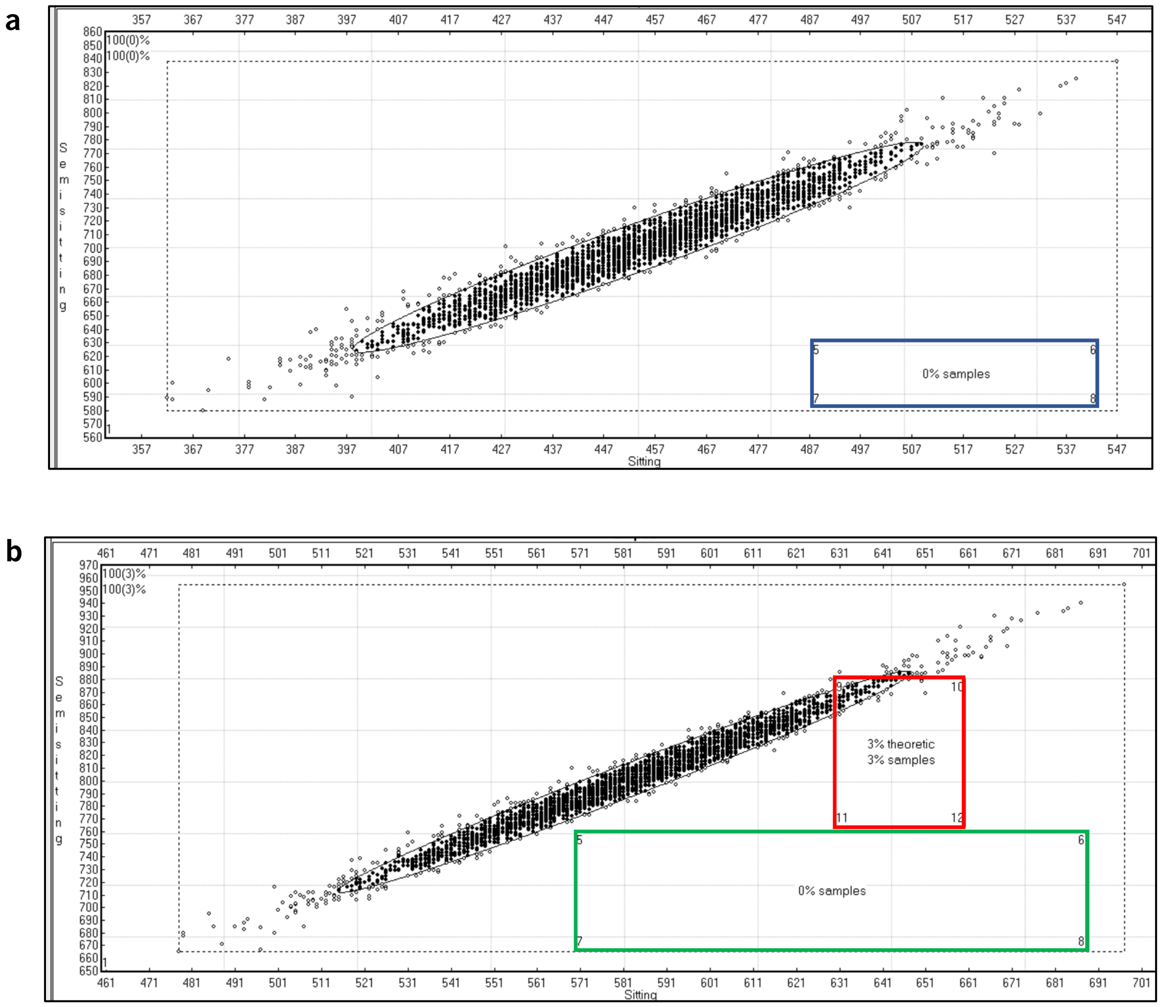


Figure 7.9. Levels of match for sitting and perching with Amazone Chair. a. sitting at a 90° and 120° trunk/thigh angle with small/blue lift; b. sitting at 105° and 135° trunk/thigh angle with medium/green and large/red lifts

As was explained previously and after the results obtained from two commercially available adjustable chairs, it is difficult to have a chair with a lift that allows to be seated at 90° trunk/thigh angle and perching at 120° or 135° trunk/thigh angle. Due to this, and not considering the use of footrest, a proposed

SH that allows users of the sample to vary between a seated posture of 105° and perching of 135° can be seen in Figure 7.10. The first, with a range of 520-800mm accommodating the first 44% and the second range of 580-870 mm accommodating a 47 % of the sample, thus between the two proposed seat heights a 91% of the total sample is accommodated. This recommendation was done thinking in the adjustable saddle chair configuration, but it can be done also with a forward slope that does not surpasses the 15°.

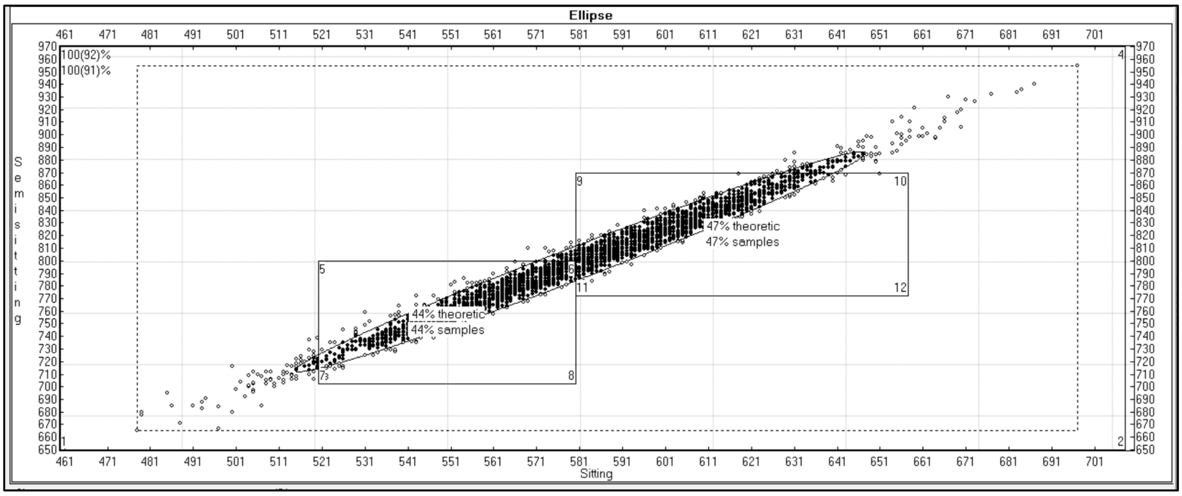
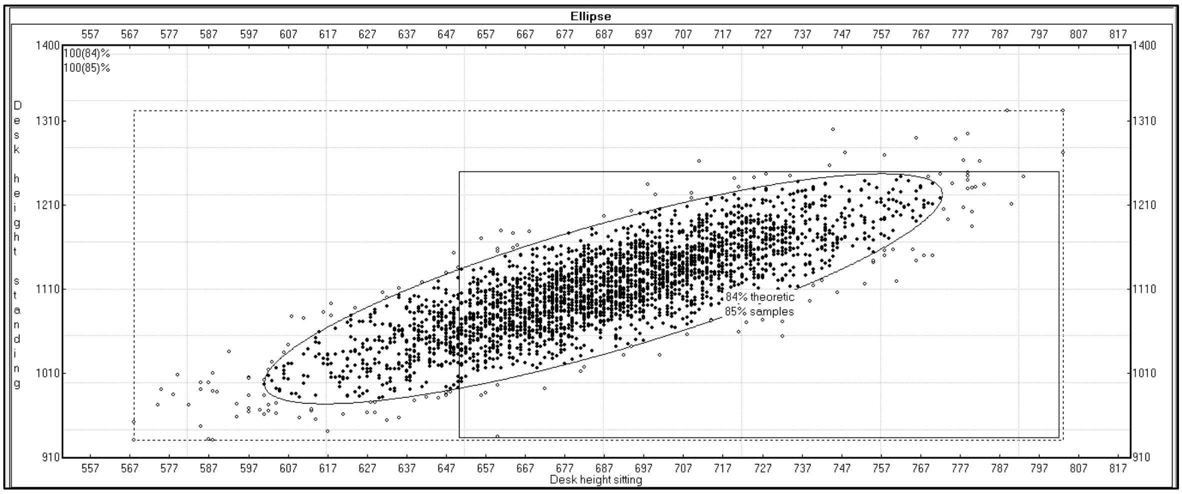


Figure 7.10. Seat proposal for sitting and perching. Sitting at 105° and 135° trunk/thigh angle

7.4.3.2. Hybrid seating adjustable desk

Figure 7.11a shows the levels of accommodation for the sample using the minimum adjustable desk heights recommended in the CEN (2011) standard (650mm - 1220mm) for sitting and standing. Note that only 85% of the sample is accommodated by the design. Figure 7.11b shows the levels of accommodation of the E-model® commercially available height adjustable desk for the sample, with a range of 620mm- 1280mm. Note that 97% of the sample is accommodated by the design.

a



b

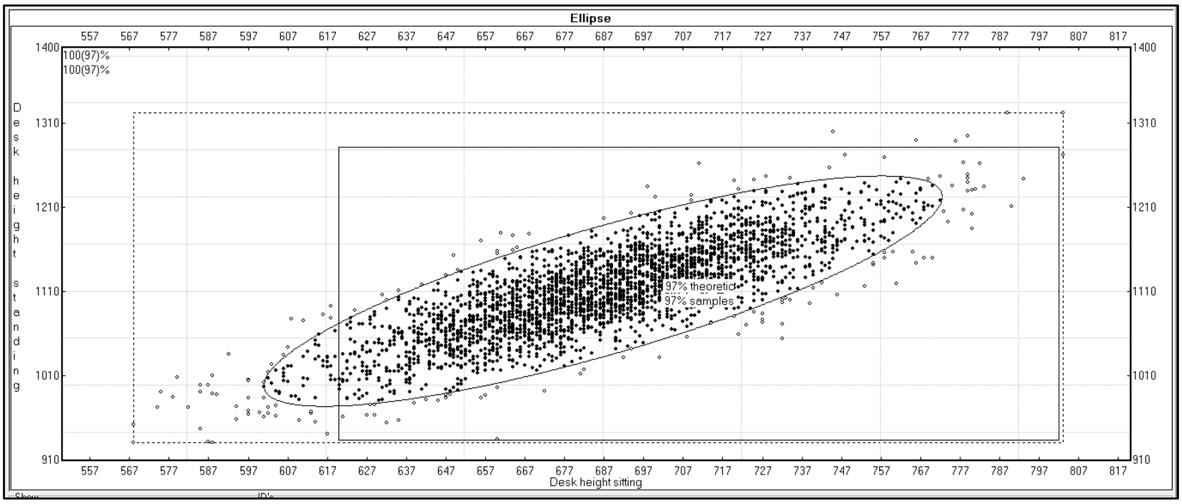


Figure 7.11. Adjustable desk height levels of match for standing a. CEN (2011) standard levels of match b. E-model® commercially available height adjustable desk

7.4.4. Sitting, Perching and Standing: comments and future applications

The current research shows that the standards used do not allow easily to design furniture for dynamic seating, which has been previously reported by Dainoff et al., (1994). Although cumulative levels of match calculated using the dimensions present in ISP (2016) and CEN (2000, 2011) standards were under 90% when seating traditionally, having a height adjustable desk coupled with an adjustable chair favoured higher levels of match. This was seen also when introducing the height adjustable desk, were DH reached nearly a 99% level of match. Regarding individual measurements, SD was the one that presented the lowest levels of match using both standards, thus recommended SD will be too short for the current sample.

With the results of testing the dimensions of available market chairs that facilitate dynamic seating seems to present ideal conditions that in practice are difficult to obtain, namely being able to seat, perch and stand with just one dimension. Furthermore, will be difficult to design a chair with a lift that allow setting at 90° trunk/thigh angle and perching 120° or 135° trunk/thigh angle without footrest. However, is important to remember that seated a 90° trunk/thigh angle it is not recommended by some authors (Bendix, 1994; Bendix & Bridger, 2004; Mandal, 1981, 1991, 1994a, 1994b). The proposed equations will allow the ergonomist and designer to define the dimension of a workstation that allow to work in sitting, perching and standing position. Finally, it is important to notice that the current criteria proposed are applicable only when the full set of raw data are available, mainly because the use of bivariate approach.

A recent review has shown that sit to stand work stations make the most significant impact on behavioural changes (i.e.: sit for less time), followed by a reduction in discomfort (Chambers et al., 2019). In the same study, other outcomes were impacted with less significance such as physiological outcomes (i.e. energy expenditure), psychological (i.e.: work satisfaction) and posture. It is likely that the relationship of sit/stand time dosage, training and follow-up had an impact on these outcomes, as reported by the authors of the previously cited review. Different interventions have tried to address the sedentary behaviour associated with office work. For instance, some interventions have aimed to increase energy expenditure through the use of dynamic chairs, despite the fact that the dynamic chair had higher levels of energy expenditure, it was still lower than 1.5 MET, which is the threshold for sedentary behaviour (Synnott, Dankaerts, Seghers, Purtill, & O'Sullivan, 2017).

The proposal made in the current study will probably aim or have a higher impact on discomfort and behaviour, since it could allow most users to alternate postures between sitting, perching and standing. In 1981, Mandal recommended a position with a 135°-trunk–thighs angle in order to favour the physiological lumbar lordosis (Mandal, 1981). Since then, it is recommended that furniture be adapted by raising the seat and inclining it forward in order to reach this reference angle.

However, this recommendation does not take into account the fact that dynamism is also essential (Fettweis et al., 2017). For instance, even a static perching posture with the use forward sloping chairs have setbacks, such as increase in pressure distribution towards the feet, if the inclination is above 15° (Corlett & Gregg, 1994; Fettweis et al., 2017). The use of forward slope chairs has also shown a higher activity of the knee and ankle extensors (Hamaoui, Hassaïne, Watier, & Zanone, 2016). The same authors concluded that sloping chairs favour a more erect posture of the spine but entails an undesirable overactivity lower limbs muscles to prevent the body from sliding. In that regard, using both a saddle chair, together with an overall height increase, which has been consistently proven to be both biomechanically better and preferred by users (Bendix, 1994; Bendix & Bridger, 2004; E. N. Corlett, 1999, 2009; Mandal, 1981, 1991, 1994b, 1994a; Mandal, 1981; Noro, Naruse, Lueder, Nao-I, & Kozawa, 2012). Furthermore the use of a saddle configuration has shown to have additional benefits such as a maintained scrotal temperature, when compared with traditional seating mainly due to the opening of the trunk/thigh angle and hips (Koskelo, Zaproudina, & Vuorikari, 2005).

Independent of previous research, the proposal of the current research should be validated with fitting trials in an experimental design, since it has been shown that not always anthropometric match insures comfort and preference(Bahrampour, Nazari, Dianat, Asghari Jafarabadi, & Bazazan, 2019). Fitting trials using both subjective and objective measurements of discomfort should be used, since the latter, such as pressure distribution measurements, electromyography or posture analysis may have some advantages compared to subjective methods, but they only assess comfort indirectly. Objective methods can generally be used as a useful addition to subjective ones (Bahrampour et al., 2019).

Highly adjustable office stations have the possibility of satisfying the adjustment needs of most end-users. However, adjustable chair functions need to be both available and known in order to be used. Since the proposal of the current research is based on adjustable chair and desk, training and reminders should be implemented in future experiments that aim to test the proposed match equation on real users (Bahrampour et al., 2019; Chambers et al., 2019). It has been shown that office workers know fewer than half of their available adjustable chair functions and use fewer than they have knowledge of, where reasons for lack of knowledge and use are complex and influenced by adjustment barriers and individual differences (Bahrampour et al., 2019).

This reinforces the need to further test the design with real users following the recommendations of Chambers et al. (2019), regarding sit stand dosage, exposure and follow up time, especially considering that it is important to give end-users the opportunity to test the chair for a period of time, since it has been shown that the short-term comfort may not always be the same as their long-term comfort (De Looze, Kuijt-Evers, & Van Dieen, 2003). Future studies should quantify pressure differences in the feet and buttocks during dynamic seating considering variance in trunk/thigh angles and seat`s shapes and height.

7.5. Conclusions

The office furniture dimensions present in both standards (national and international) used in the current research did not match the dimension of the sample. Dynamic seating, although beneficial for users is difficult to achieve with less adjustable office furniture, which is quite logical. Regarding adjustability the most significant issue had to do with the fact that if users wish to sit, perch and stand, both desk and chair need to be adjustable, being the latter harder to address with the dimensions of the office chairs used. The main issue was that none of the chairs had a lift that could match most of the sample for traditional seating and perching. In fact, two heights needed to be used to match most of the sample, where the sitting component needed to be set at 105° trunk/thigh angle, which could be more beneficial than the cubist approach of 90° trunk/thigh angle. In order to perch, new equations are presented to either use higher saddle chairs or forward sloped chairs. The resulting designs deriving from these equations need to be tested for both subjective and objective measures in the field/lab in order to understand more in depths the effects on the lower limbs.

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CHAPTER 8| Applied anthropometrics for common industrial settings design: working and ideal manual handling heights.

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Anthropometrics has been used extensively for designing safe and sustainable products and workplaces, however, it is common that designers need straightforward guidelines and dimensions for specific design situations, which are often lacking. Anthropometric data are usually presented in tables summarizing percentile values of a specific population, separated by gender, which makes it difficult for designers to create applications for mixed populations, such as industrial settings. Using a recently collected anthropometric database of Chilean workers (male and female), dimensions recommended by international standards for working heights, depths and ideal manual handling height are tested with univariate and bivariate methods. Alternative dimensions are presented for both adjustable and not adjustable designs. Additionally, procedures to combine samples and knowing how many users are matched by a particular design are explained using the sample data. As expected, adjustable designs proved to achieve higher levels of match, while the not adjustable dimensions recommended by ISO presented low levels of match. Furthermore, the not adjustable recommendation achieved 83% of match and the inclusion of a platform of 50mm increase match to the desired levels (90%). Finally, the z-score equation proved to be a useful tool to know the percentages of the population that are matched when having a particular design dimension.
Relevance to industry
Dimensions for working heights, depths and ideal manual handling heights are provided for Chilean workers, which is currently not available. A method to determine the match percentage of a population is explained, in order to assess match when only having summarized anthropometric tables and the dimension of the design itself.

Keywords: anthropometry, assembly task, manual handling, working height

8.1. Introduction

Ergonomics and human factors as a scientific discipline aims to achieve safe and productive workplaces for everyone (Kroemer, 2006). In that regard, several factors can either enhance or hinder health and performance, were the physical layout and dimensions of the working space is a critical one (Kroemer & Grandjean, 1999; Mandal, 1991; Marras & Kim, 1993; Molenbroek, Kroon-Ramaekers, & Snijders, 2003; Rohlmann, Zander, Graichen, Dreischarf, & Bergmann, 2011). Working spaces and tools need to be suited to the end user´s anthropometric dimensions in order to obtain healthy and productive working places (Marras & Kim, 1993; Pheasant & Haslegrave, 2006; Pheasant & Steenbekkers, 2005), but additionally not accommodating end user`s anthropometry with the design can compromise also sustainability, mainly because of reduced raw material consumption, increasing usage lifetimes and incorporating ethical human resource considerations in design (Nadadur & Parkinson, 2013). Several applications of anthropometry are reflected in a variety of reports and applications such as school furniture (Castellucci, Catalán, Arezes, & Molenbroek, 2016; Castellucci, Arezes, & Molenbroek, 2014, 2015; Mokdad & Al-Ansari, 2009), agricultural tools (Dewangan, Owary, & Datta, 2010; Syuaib, 2015b, 2015a), car assembly (Castellone, Spada, Caiazzo, & Cavatorta, 2017), personal protective equipment (Choi, Zehner, & Hudson, 2009; Coblentz, Mollard, & Ignazi, 1991; Hsiao, 2013; Laing, Holland, Wilson, & Niven, 1999; K. M. Robinette & Branch, 2008; Stirling, 2005), public transport seats (Molenbroek, Albin, & Vink, 2017; Porta, Saco-Ledo, & Cabañas, 2019), domestic settings (Dawal et al., 2015) and even space shuttles and suits (NASA, 1978).

Additionally, some of the most comprehensive assessment methods for industrial manual handling, such as NIOSH original equation and subsequent updates, have used referential anthropometry in their rationale (Dempsey, McGorry, & Maynard, 2005; Frost, 2011; Waters, Occhipinti, Colombini, Alvarez-Casado, & Hernandez-Soto, 2009; Waters, Lu, & Occhipinti, 2007; Waters, Putz-Anderson, Garg, & Fine, 1993). For example, NIOSH`s variable task Lifting Index (Waters, Occhipinti, Colombini, Alvarez-Casado, & Hernandez-Soto, 2009), considers both horizontal and vertical distances of load displacement that when surpassed, significantly increases the risk of injury for the lower back. This is mainly attributed to the biomechanics of handling loads outside "safe" zones that use anthropometry as limits. According to NIOSH, if the horizontal distance is more than 63 cm, it is likely that most people must handle the load further away from their center of mass beyond the anthropometric dimensions minimum functional grip, thus increasing the risk. Similarly, if the vertical distance is above 175 cm, the load will probably be handled above shoulder height by most subjects, increasing even further the risk of injury. Liberty Mutual uses force application height, similarly based on anthropometrics, differentiating heights and risk level for both females and males (Snook & Ciriello, 1991).

Commonly, the anthropometric dimensions are extracted from tables which expressed the distribution of the population in percentiles, which should be used by designers and ergonomics' specialist to set preventive recommendations, were in an ideal design process anthropometrics are compared with relevant product and workplace measurements (Hanson, Sperling, Gard, Ipsen, & Olivares Vergara, 2009; Pheasant & Haslegrave, 2006). This approach is no short of limitations, since it depends on the design and its associated dimensions to be either simple or more complex. For example, when design involves only one dimension, (i.e. door clearance or reaching of an object), using the biggest or smallest percentile value ensures the match for almost everyone (Kroemer, 2006). In practice however, there are other cases when more than one dimension needs to be used, then the process is more complex and requires using both minimum and maximum values of different anthropometric dimensions, such as attaining certain postures for example, thus the interaction of different anthropometric dimensions and their specific values requires more complex calculations (Kroemer, 2006; Robinette, 2012). In those applications, two (bivariate) or more (multivariate) parameters must be considered since two/multiple anthropometric dimensions are relevant to the function of a product. In such cases, standard anthropometry tables could not adequately address the design applications involving bivariate or multivariate applications. Examples of bivariate anthropometric procedure are the design of garments such as helmets, which requires head length and head breadth dimensions and the design of respirators require face length and face width dimensions. Generally, the greater that the number is of involved dimensions, the more complex that the product design process is (Dianat, Molenbroek, & Castellucci, 2018).

Although following the above stated processes can ensure optimal fit, this is the ideal situation, and often designers do not follow this process and prefer ready to use data for specific populations in order to set the design recommendations (Ranger, Vezeau, & Lortie, 2019). Chilean workers anthropometric dimensions used until today were collected more than 20 years ago, thus they are probably out of date. Additionally, at the moment, there are no specific dimensions recommended to fit Chilean working populations in common industrial tasks such as manual handling of loads, assembly lines, among others.

The aim of the current paper is to apply the anthropometric dimensions to two common industry related designs, namely production line heights and depth as per task type and manual material handling heights, using a newly constructed Chilean workers database. Additionally, recommendations for the targeted populations and general straight forward calculation methods are provided for designers to easily calculate working heights for any population that has standard anthropometric tables.

8.2. Materials and methods

8.2.1. Sample

During 2016 anthropometric dimensions were collected by the authors of this article as a part of a larger research project, ending up with 32 anthropometrics measures. Data were collected on 2,946 workers (600 female and 2,346 male) from the two most populated regions of Chile (Valparaíso and Metropolitana) distributed by 9 economic activity sectors (Agriculture and fishing; Mining; Manufacturing; Electricity; Construction; Commerce; Transport and communications; Financial services; and Communal and personal services).

Measurements were collected manually by specialized teams of physiotherapists who underwent training and performed pilot studies to assess both inter- and intra-measurer reliability, in order to obtain high quality measurements (Viviani et al., 2018). The full list of values of the sample and more details about the procedure can be seen in a recent publication (Castellucci et al., 2019).

8.2.2. Anthropometric dimensions

The standard procedure proposed by ISO 7250-1 (2008) was followed in the collection of the anthropometric measurements. The procedure indicates that the anthropometric measures need to be collected from the right side of the subjects' body while they are sitting in an erect position on a chair with a horizontal surface with their legs flexed at a 90° angle and with their feet flat on the ground. During the measurement process, the subjects wore no shoes and had light clothing (shorts and t-shirts). The following dimensions were used in the current research:

1. <u>Shoulder height standing (ShStand):</u> vertical distance from the floor to the acromion.
2. <u>Elbow height standing (EHStand):</u> taken with a 90° angle elbow flexion. as the vertical distance from the bottom of the tip of the elbow (olecranon) to the floor.
3. <u>Elbow grip length:</u> horizontal distance from back of the upper arm (at the elbow) to grip axis, with elbow bent at right angles.
4. <u>Grip reach; Forward reach:</u> horizontal distance from a vertical surface to the grip axis of the hand while the subject leans both shoulder blades against the vertical surface.
5. <u>Knuckle height (KnuH):</u> vertical distance from the floor to metacarpal III (i.e. the knuckle of the middle finger).
6. <u>Knee height (KH):</u> vertical distance from the floor to the highest point of the superior border of the patella.

8.2.3. Procedure

Mainly two methods were used: univariate and bivariate methods. A univariate approach was used for assessing match and elaborating proposals for working heights in standing assembly tasks according to task type (high manual and visual precision, moderate and high force). Within that framework, methods of limits were used, which is a model or analogue of the fitting trial, in which anthropometric criteria and data are used as substitutes to 'stand for' the subjective judgements of real people (Pheasant & Haslegrave, 2006). It is worth mentioning that, even if only one dimension is used, the method of limits in this case is 'two-way', were both an upper and lower limit need to be respected in order to achieve the desired effect, thus it behaves as a bivariate dimension.

As checking method, percentile values through the use of specific criteria were used, since this is quite common were designers only have the summarized tables and not the raw data. Comparisons were made against dimensions present in ISO 14738:2012 for both adjustable and fixed designs. In fixed designs a bigger range was established in order to allow higher match percentages. Quoting Pheasant & Haslegrave, (2006) 'Since we may reasonably assume that users may be prepared to accept less than absolute perfection, we may well find it useful to consider two further zones above and below the optimum, which we would characterize as ‘satisfactory but not perfect’. Additionally, a proposal is made, and, in both cases, the z-score equation was used to start from a design and then assess the levels of match (see section 2.3.1.1 for details):

$$Z(p) = \frac{Z(p) - \bar{x}}{s}$$

In order to represent visually the levels of match, ellipses methods to further test the levels of match using the raw data were performed on the key anthropometric measure, Elbow height standing (EHStand), crossing it against Stature, for the mere reason that the method itself requires the use of two anthropometric dimensions.

Both bivariate and methods of limits and approaches were used for ideal manual handling heights and depths, respectively (Figure 5a). For ideal manual handling heights, the bivariate approach was used on the two key anthropometric dimensions, EHStand and KnuH. For depths, a one-way criterion was used, and method of limits was applied using percentiles. As mentioned in the introduction, using percentile values is quite simple, as only the selection of one dimension will ensure the recommended match percentage as long as it does not conflict with the other ones. In the case of the current study, it can be seen in the use of the depths of ideal manual handling, where if the designer wishes to accommodate most users, the 5th percentile for females (smallest) for Elbow grip length and Grip reach should be used, thus if the person with the smallest reach is matched so are the ones with the largest reach.

A calculation method is explained through example (see section 2.3.1.1) using working heights for tasks with high force requirements as a reference for a very common problem often needed to be tackled by designers. The problem arises when they (designers/ergonomists) need to know how many people are matched by a specific design dimension, but they only have the anthropometric tables and not the raw data.

For all of the values presented that consider height, a shoe correction value should be used between 2.5 to 4 cm depending of the footwear that is being used in any particular work setting, especially considering the high variability of shoes needed or used in industrial contexts, in this study a 3cm shoe correction (SC) was used since the focus is industrial settings (ISO, 2012). For any application (uni- or bivariate), a level of accommodation of 90% was deemed acceptable (Bridger, 2003).

Design recommendations were made for the entire sample (mixed females and males) for both assembly tasks and ideal manual handling heights/depths. In the case of ideal manual handling, recommendations were also done for females and males only.

8.2.3.1. Working heights and depth

It is important to distinguish between working height and work-surface height. The former may be higher than the latter if hand tools or other equipment are being used in the task (Pheasant & Haslegrave, 2006). Other authors refer to working height as hand reference point (HARP) (Helander, 2006). It is possible that the working height may be below the work surface, for example when someone is washing dishes at their kitchen sink, the task is performed at the bottom of the sink (working-surface height) but at the working height of the object that is being washed. Therefore, the height of the object being manipulated should be considered for designing working height.

Different recommendations have been made for different task type. Each one will be detailed in the following subsections

8.2.3.1.1. Working height for tasks with high force requirements

For these types of tasks, ISO standard 14738:2012 considers criteria for adjustable and fixed designs (see values on table 2):

– Adjustable:
    - Min: 0.9 x EHStand (P5) + SC

    - Max: 0.9 x EHStand (P95) + SC
- Not adjustable:
    - 0.9 x EHStand (P95) + SC

For the current research the criteria set by (Helander, 2006) for tasks with high force requirements were used:

- Max: EHStand -100 + SC
- Min: EHStand - 200 + SC

Remember that as for all fixed designs and according to Pheasant & Haslegrave, (2006) two further zones extending 50 mm above and below the optimum were used.

A common problem, which needs to be addressed by designers is knowing how many potential users are matched by a particular design dimension (i.e.: working height of "x" cm). This can be difficult to know, especially when only having summarized anthropometric data of separate males and females. In order to "reverse engineer" how many people are match using a particular dimension, the z-score or distribution is needed. Simply put, a z-score (also called a standard score) gives an idea of how far from the mean a data point is. But more technically it's a measure of how many standard deviations below or above the population mean a raw score is. When data distribute normally, as do almost every anthropometric dimension, z-scores allow us to determine any percentile value using the mean and the standard deviation. Any statistics or even the internet can be sourced for the z-score, which can be associated to determine to which percentile a specific value corresponds.

The first equation can be used to define how many people will match, for example, a particular current working height (remember the working height is different to working surface height). Let say that a worker in a production line needs to move a heavy box. The surface height is 700 mm and the box´s handles are at 210 mm from the bottom, the working height will be 910 mm. This example is not arbitrary, since is the actual calculated and recommended value for tasks with high force requirements of the current research for the sample, in fact the entire results and accommodation rates can be seen further down in table 8.2. Figure 8.1 depicts more clearly the situation that will be addressed in the example.

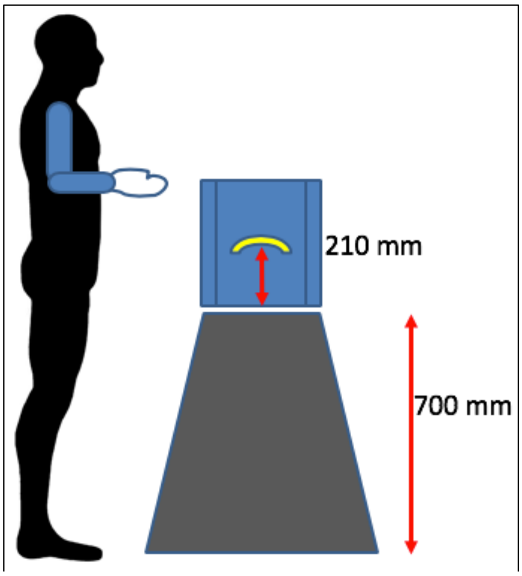


Figure 8.1. Example for working height calculation

The question to be answered by the example is, how many workers will be matched with a working height of 910 mm for this type of task? (The value corresponds to the fixed proposal, see 8.3.2.1). It is already known that EHStand is the key anthropometric dimension. Since a mixed population was considered a combined EHStand for the entire sample of 1029±54.4 was used. Details about this and other combined dimensions can be seen in Table 8.1 and calculation on combining sample dimensions in section 8.3.3. Therefore, the steps to follow are:

1. Determine the criteria. The type of work needs high force and the principles to define the dimensions are the ones used previously, considering the extension of 50mm up and down for acceptable zones:

- Acceptable high: max limit: EHStand -50 + SC; min Limit: EHStand -100 +SC
- Optimal: max limit: EHStand -100 + SC; min: EHStand -200 +SC
- Acceptable low: max limit: EHStand -200 + SC; min Limit: EHStand -250 +SC

2. Calculate/replace the new values to define the z-value (percentile):

$$Z(p) = \frac{Z(p) - \bar{x}}{s}$$

- Acceptable high:

- max limit: 910+50-30: 930

$$Z(p) = \frac{930 - 1030}{54.4}$$

$$Z(p) = -1.83$$

After retrieving from the z-score table: it corresponds to P3

- min limit: 910-30+100: 980

$$Z(p) = \frac{980 - 1029}{54.4}$$

$$Z(p) = -0.90$$

After retrieving from the z-score table it corresponds to P18, therefore a total of 15% (P3-P18) of the population will matched by this condition.

- Optimal:
  - max limit: 910-30+100: 980

$$Z(p) = \frac{980 - 1029}{54.4}$$

$$Z(p) = -0.90$$

After checking in the table, the respective z-score corresponds to P18

- min limit: 910-30+200: 1080

$$Z(p) = \frac{1080 - 1029}{54.4}$$

$$Z(p) = 0.93$$

After checking in the table, the respective z-score it corresponds to P82, therefore a total of 64% (P18-P82) of population is matched by the optimal condition

- Acceptable low:
  - max limit: 910-30+200: 1080

$$Z(p) = \frac{1080 - 1029}{54.4}$$

$$Z(p) = 0.93$$

After checking in the table, the respective z-score it corresponds to P82

  - min limit: 910-30+250: 1130

$$Z(p) = \frac{1130 - 1029}{54.4}$$

$$Z(p) = 1.85$$

After checking in the table, the respective z-score it corresponds to P97, therefore a total of 15% (P82-P97) of population is matched by the acceptable low condition

8.2.3.1.2. Working height for tasks requiring moderate level of force and precision

Similar to precision tasks, ISO standard 14738:2012 recommends both adjustable and fixed design criteria, which can be seen below (see values on table 8.2.):

- Adjustable:
  - Min: EHStand (P5) + SC
  - Max: EHStand (P95) + SC
- Not adjustable:

- EHStand (P95) + SC

For fixed designs and according to Pheasant & Haslegrave, (2006) two further zones extending 50 mm above and below the optimum were considered. With that rationale in mind, the following criteria will be used:

- Max: EHStand - 50 + SC
- Min: EHStand - 100 + SC

8.2.3.1.3. Working height for high visual and/or precision requirements

ISO standard 14738:2012 considers design equations for both adjustable and fixed designs for this type of task (ISO, 2012) (see values on table 8.2). They use Elbow height standing (EHStand) as the baseline anthropometric dimension. The criteria are:

- Adjustable:
    - Min: 1,1 EHStand (P5) + SC
    - Max: 1,3 EHStand (P95) + SC
- Not adjustable:
    - minimum of 1315mm

On the other hand, Pheasant & Haslegrave, (2006) for delicate manipulative tasks (including writing) height (wrist support will generally be necessary) use different criteria and will be applied in the current research:

- Min: EHStand +50 + SC
- Max: EHStand + 100 + SC

8.2.3.2. Manual material handling height and depths

Additionally, general guidelines are provided regarding ideal and acceptable manual handling. Those general ranges are:

- Vertically (K. H. E. Kroemer & Grandjean, 1999)
    - Ideal (between knuckle height standing and elbow height standing)

- Acceptable low (between Knee height and knuckle height standing)
- Acceptable high (between elbow height standing and shoulder height standing)

- Horizontally (HSE, 2016)
  - Ideal (within Elbow grip length P5)
  - Acceptable (within Grip reach; Forward reach 5th percentile).

From that point of view and using bivariable methods (ellipse) the recommended heights were calculated. Depths (horizontal) distance as mentioned previously considered the 5th percentile.

8.3. Results and discussion

8.3.1. Anthropometric dimensions

Dimensions used and their associated percentile values can be seen in Table 8.1. Where other percentile values where used, the reader can easily calculate them using the z-score distribution using SD and average values (Bridger, 2003; Pheasant & Haslegrave, 2006), as it will be discussed further down in this section.

Table 8.1. Anthropometric dimensions used

Anthropometric measurements	Female (mm) (n:600)				Male (mm) (n:2346)				Mixed (mm)(n:2946)			
	Mean	SD	P5	P95	Mean	SD	P5	P95	Mean	SD	P5	P95
Shoulder height standing	1316.0	55.8	1221.1	1407.0	1416.2	59.9	1320.0	1518.0	1396.0	71.5	1278.8	1513.5
Elbow height standing	977.3	46.3	902.0	1053.9	1041.9	48.3	965.0	1123.0	1029.0	54.4	939.6	1118.4
Elbow grip length	311.4	17.7	282.0	341.0	340.3	18.5	311.0	371.0	335.0	21.7	298.9	370.1
Grip reach; Forward reach	681.5	36.1	625.1	749.0	740.9	39.0	680.4	807.0	729.0	45.2	654.8	803.3
Knuckle height	711.4	34.8	656.1	771.0	758.8	38.3	699.0	824.0	749.3	42.2	680.1	818.5
Knee height	482.8	23.5	445.0	524.0	522.6	25.7	481.0	567.0	514.6	29.9	465.6	563.7

8.3.2. Working heights

Table 8.2 summarizes the results for the mixed population for the different tasks. As it can be observed the ranges indicated in the ISO standard for adjustable working heights provides higher levels of match than the proposal, except for tasks with moderate force requirements, when the match % falls below the acceptable criteria of 90%. Therefore, the proposal, with much less range of adjustability, will provide an overall complete match independent of the task than the ISO dimensions.

Regarding fixed designs, it can be noticed that the levels of match of the ISO standard drop considerably in all task type when using a single height. This is no surprise, since Chilean workers' anthropometrics was shown to be significantly different of other populations used in ISO standards (Castellucci et al., 2019). Also notice in table 2 that ISO fixed dimension practically does not match any of the sample, with match percentages from 0% to 10%. In that regard, considering the proposals per each task type, the proposal has an 83% match in high visual and/or manual precision and Moderate force and precision tasks when considering cumulative match for both acceptable (high and low) and optimal heights. High for tasks with high force requirements match 94% of the sample when considering cumulative match for both acceptable (high and low) and optimal heights. Although not ideal, 84% match is very good for match for using just one design. In the current scenario adding up a platform of 50mm could accommodate remaining 7% users to attain adequate levels of match, as shown in Figures 3e and 4e. Other option can be the use of having an additional size (grading). Remember that even though only EHStand is used this limit behaves as a bivariate, since it is two-way (upper and lower limits)

Table 8.2. Working heights summary per task type

Type of task	ISO 14738				Proposal			
	Adjustable		Fixed		Adjustable		Fixed	
	Size (mm)	Match	Size (mm)	Match	Size (mm)	Match	Size (mm)	Match
High force	867-1105	94%	1075	AL: 0% (>P100) O: 1% (P98->P100) AH: 10% (P88-P98)	770-1050	90% (P5-P95)	910	AL: 15% (P82-P97) O: 66% (P18-P82) AH: 15% (P3-P18)
Moderate force and precision (light assembly)	960-1225	84% (P18->P100)	1195	AL: 0% (>P100) O: 0% (>P100) AH: 0% (>P100)	870-1100	90% (P5-P95)	985	AL: 23% (P68-P92) O: 36% (P32-P68) AH: 24% (P8-P32)
High visual and/or manual precision requirements	1053-1584	97% (P2->P100)	1315	AL: 0% (>P100) O: 0% (>P100) AH: 2% (>P100)	1020-1250	90% (P5-P95)	1135	AL: 23% (P68-P92) O: 36% (P32-P68) AH: 24% (P8-P32)

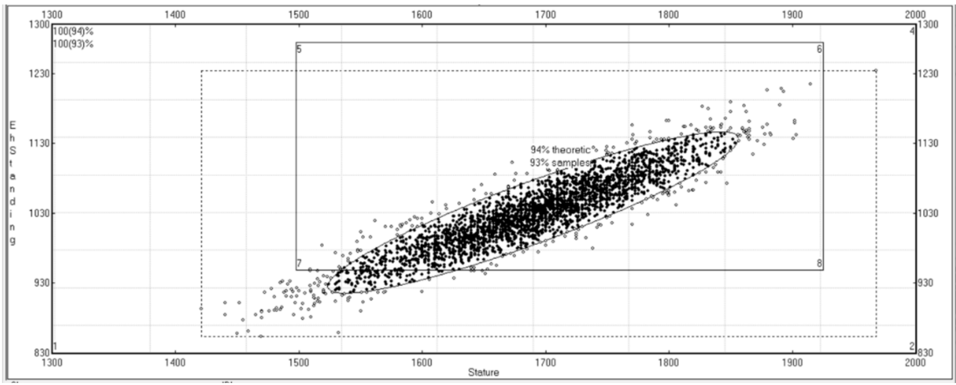
AL: acceptable Low, O: optimal, AH: acceptable high, %: results obtained with ellipses; percentile results obtained with z-score equations

8.3.2.1. Tasks with high force requirements

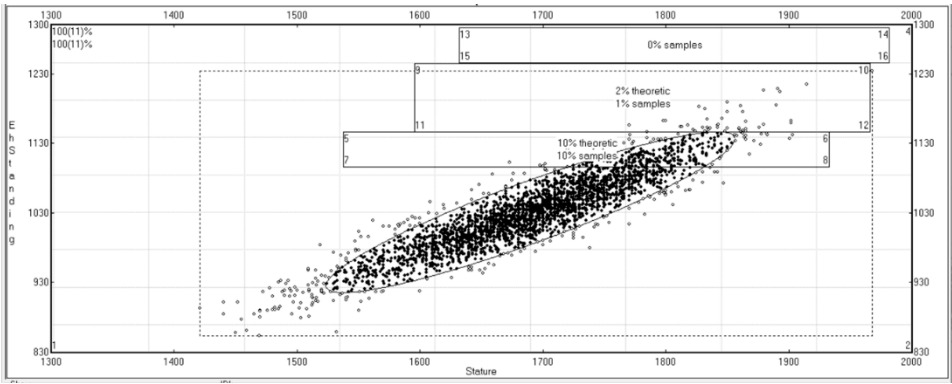
Figure 8.2 shows the ellipse analysis for tasks with high force requirements. Note from Figures 2a and 2c that ISO standard achieves higher levels of match (94%) than the proposal (90%) when using an adjustable design. Therefore, if adjustability is used a range considering at least the range in the proposal should be used, ranging from 770-1050 mm. As it can be seen in Figure 8.2b and 8.2d, using the single height of 910 mm in the proposal will ensure a 93% cumulative match for the sample, when considering acceptable (high and low) and optimal levels.

Figure 8.2. Working height match levels (%) for tasks with high force requirements a) ISO adjustable (867-1105mm range). B) ISO not adjustable (1075 mm) c) adjustable proposal (770-1050 mm). d) not adjustable proposal (910 mm)

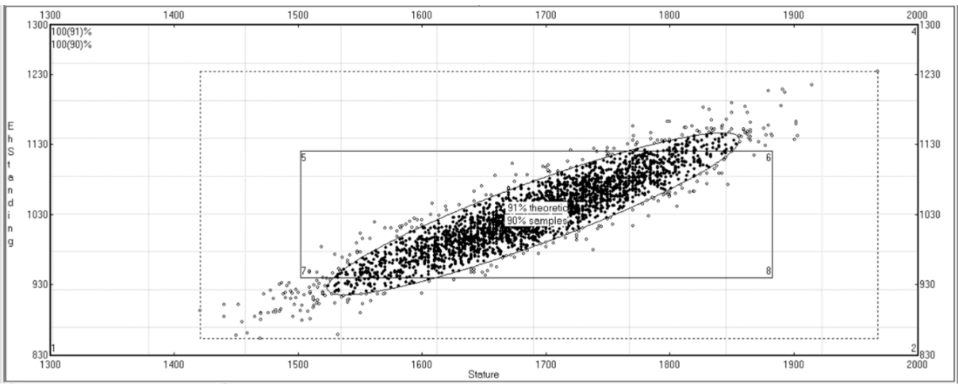
a)



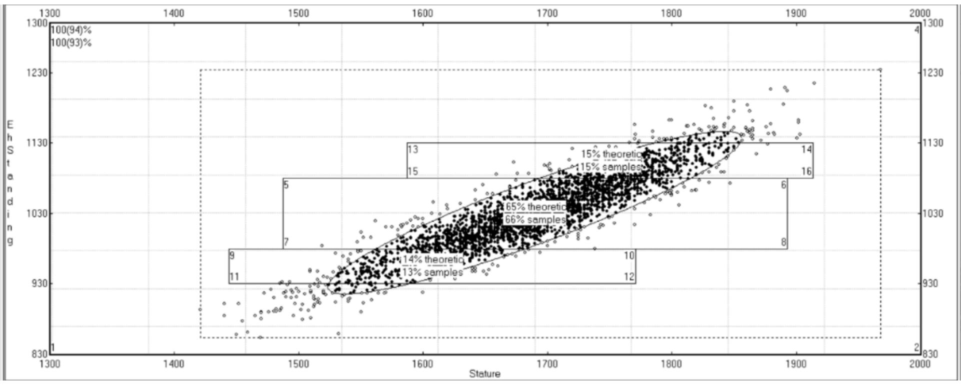
b)



c)



d)

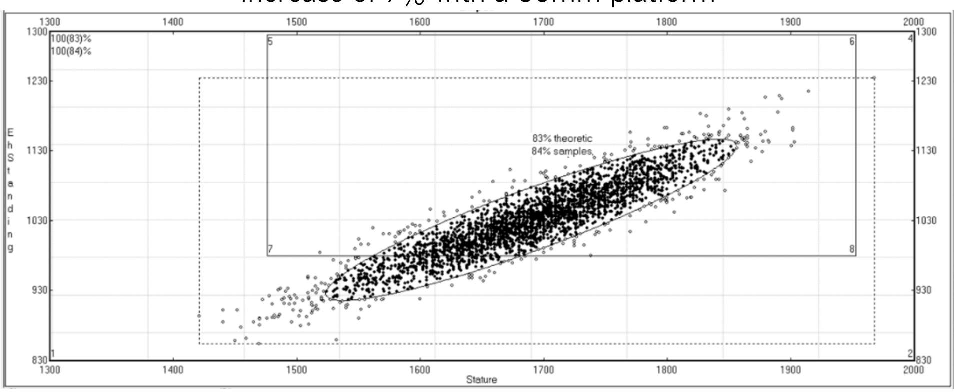


8.3.2.2. Tasks requiring moderate level of force and precision

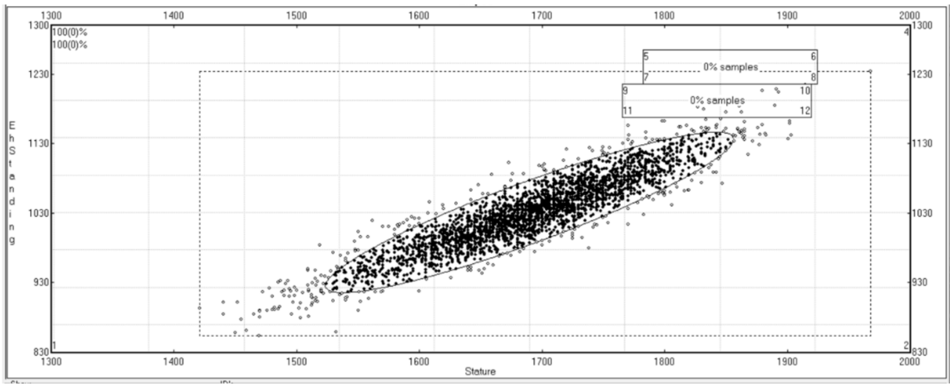
Figure 8.3 shows the levels of match for tasks requiring moderate level of force and precision considering a mixed population (female and male). Note from Figures 8.3a and 8.3c, that the levels of match using adjustability are adequate only with the proposal (90%), when using a range between 870-1100mm, since the range in the ISO standard of 960-1225mm only accommodates 84% of the sample. Note from Figures 3b and 3d, that the ISO fixed dimension matches no one in the sample, while cumulative fit considering the proposal provides an 83% match considering acceptable (high and low) and optimal heights when using a unique height of 985 mm. Adding up a 50 mm platform so that smaller workers can stand, will increase match percentage by 7%, thus obtaining a 90% match (see Figure 3e) An additional benefit is that 23% of the workers will fall on optimal range if using the same design.

Figure 8.3. Working height match levels(%) for tasks requiring moderate level of force and precision. A) ISO adjustable (960-1225mm range). B) ISO not adjustable (1195 mm) c) Adjustable proposal (870-1100mm). d) not adjustable proposal (985 mm) e) match increase of 7% with a 50mm platform

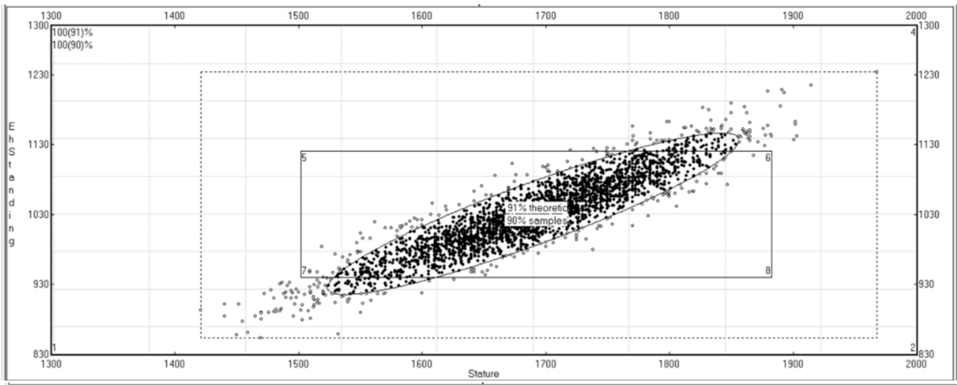
a)



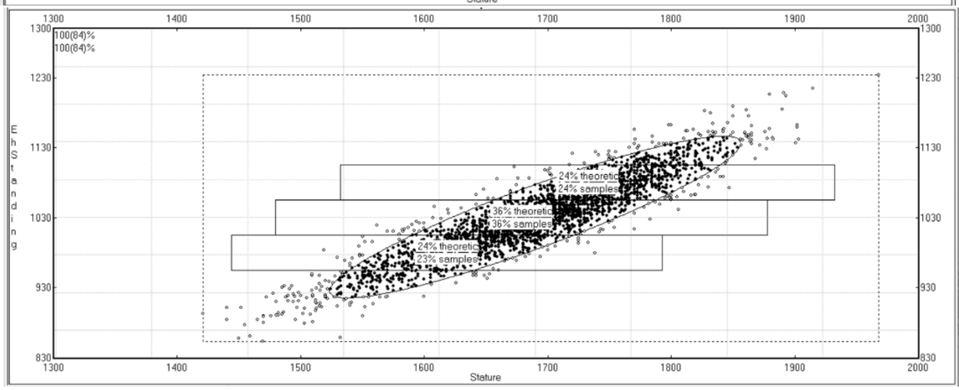
b)



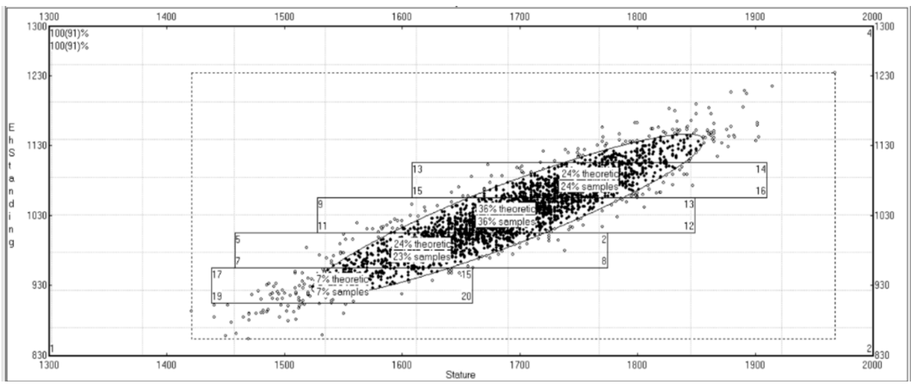
c)



d)



e)



8.3.2.3. Tasks with manual precision and visual detail

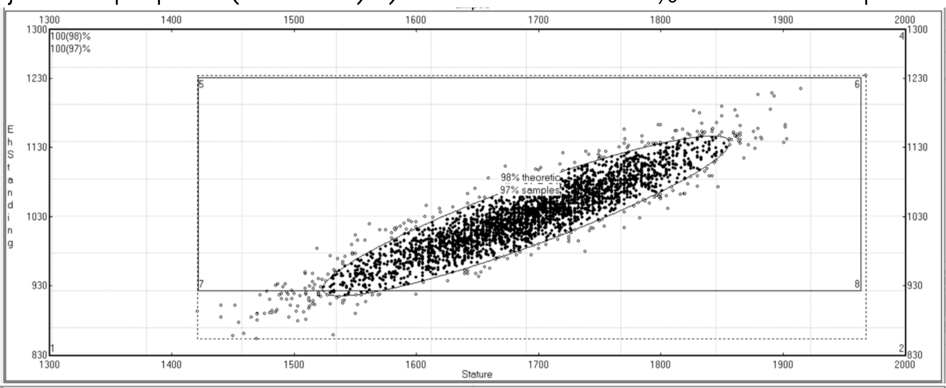
Figure 8.4 shows the use of ellipses (bivariate) analysis for tasks with high vision and manual precision requirements.). Note from Figures 8.4a and 8.4c that ISO provides higher level of match (97%) than the proposal (90%) when considering adjustable height.

If adjustability is an option, heights that range at least between 1020-1250 mm should be used.

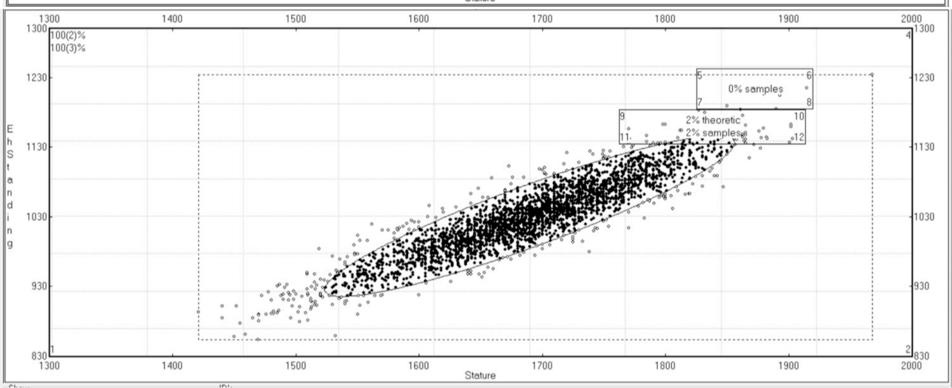
From figures 8.4b and 8.4d, can be observed that the best scenario is the one of the proposals, with a single size of 1135 mm, since the ISO recommended dimension only matches 2% of the sample. Figure 8.4d shows that when considering both acceptable (high and low) and optimal heights, 83% of the sample will be matched with the fixed proposal. Adding up a 50 mm platform so that smaller workers can stand, will increase match percentage by 7%, thus obtaining a 90% match (see Figure 8.4e). An additional benefit is that 23% of the workers will fall on optimal range if using the same design.

Figure 8.4. Working height match levels (%) for manual and visual precision tasks. A) ISO adjustable b) ISO not-adjustable. C) adjustable proposal (range 1020-1250mm). d) not adjustable proposal (1135mm) e) match increase of 7% with a 50mm platform

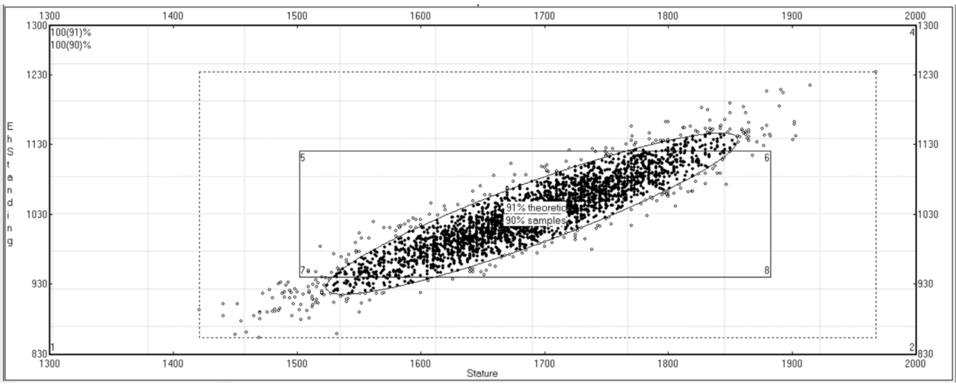
a)



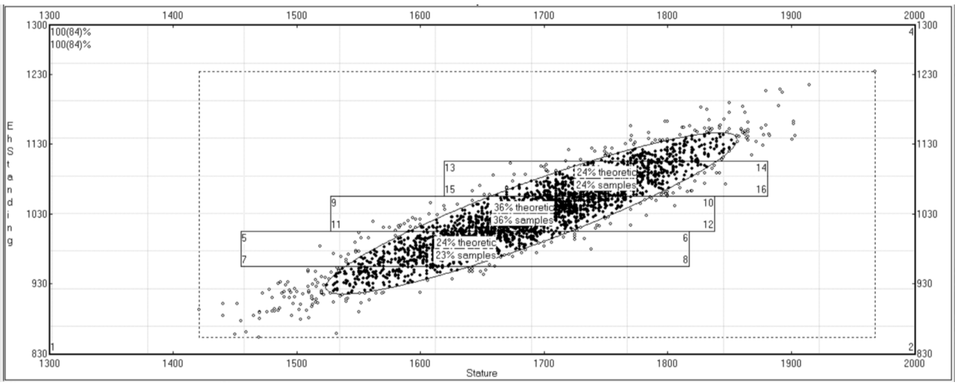
b)



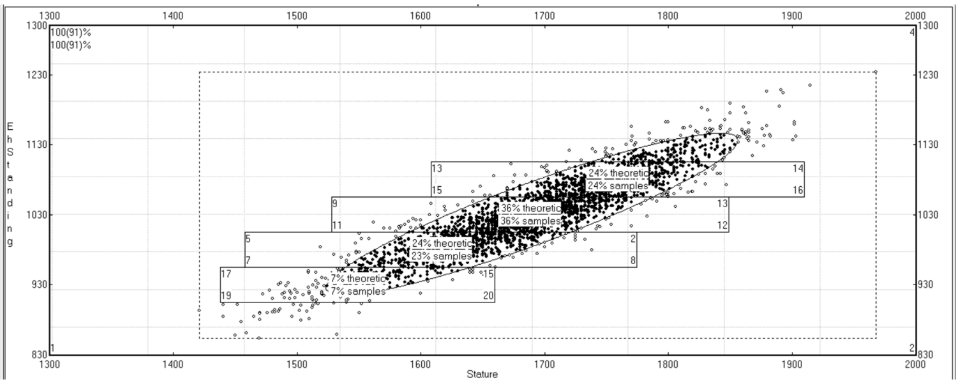
c)


100(91)%
100(90)%
91% theoretic
90% samples
Stature

d)


100(84)%
100(84)%
24% theoretic
24% samples
36% theoretic
36% samples
24% theoretic
23% samples
Stature

e)


100(91)%
100(91)%
24% theoretic
24% samples
36% theoretic
36% samples
24% theoretic
23% samples
7% theoretic
7% samples
Stature

8.3.3. Ideal manual material handling heights and depths

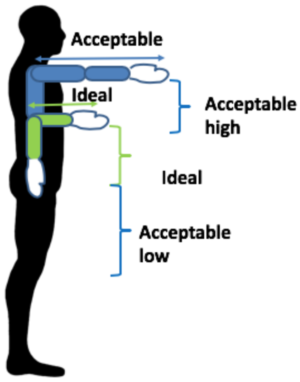
Figure 8.5a shows graphically the dimensions used, were brackets represent acceptable (blue) and ideal (green) heights. Similarly, pointed arrows represent horizontal or depths. Note that for horizontal (depths) distances for manual handling are determined by the 5th percentile for females (smallest) of Elbow grip length (green) and Grip reach (blue) since if the person with the smallest reach is matched so are the ones with the largest reach. Therefore, a depth between 341mm (5th female Elbow grip length) and 749mm (5th female Grip reach) will ensure that most of the sample performs manual handling safely when considering depth.

Figure 8.5b shows the match results for ideal manual handling selecting higher and upper limits using both smaller (i.e. 5th percentile EHStand female: 902 mm) and larger percentiles (i.e. 95th percentile KnuH male: 824 mm), generally a wider percentage of the population will be matched than just 90%, reflecting that in those scenarios, where there are no conflicting measures, including both the smallest and the biggest users, causes a match percentage increase (Robinette, 2012). In the other hand, figure 8.5c shows that the match % for ideal manual handling heights using the same principles with the combined data of the entire sample (5th percentile: 939.6 and 95th percentile: 818.5; 90% match) produces lower levels of match. The reader may believe that then why it is necessary to use combined data if match levels are lower? The answer is further developed in section 8.3.4, but in summary combined data allows to know/calculate the percentage of total users (both genders) that are matched when having a design`s dimension. more easily.

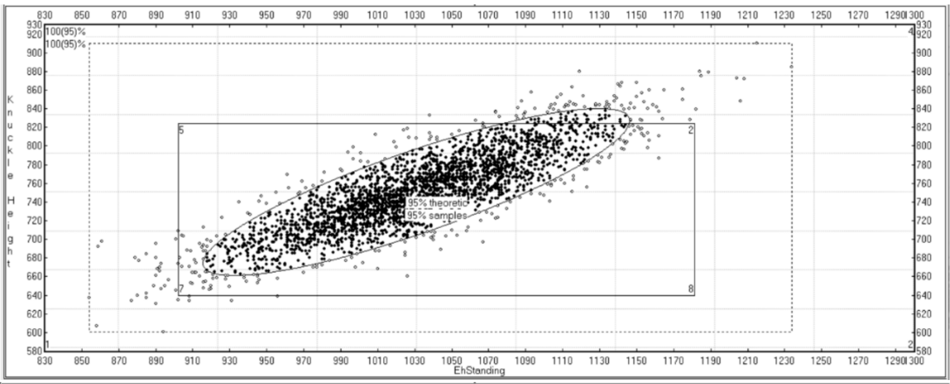
Table 8.3 shows ideal heights for a mixed, female and male populations. Note from Table 8.3 that the ideal range of heights for manual handling is an inferior limit for mixed population of 818.5 mm (95th percentile KnuH) and upper limit of 939.6 (5th percentile elbow height standing).

Figure 8.5. Ideal manual handling heights and depths a) acceptable (blue) and ideal (green) heights and depths b) Ideal manual handling height match using gender specific c) ideal manual handling height match using mixed population

a)



b)



c)

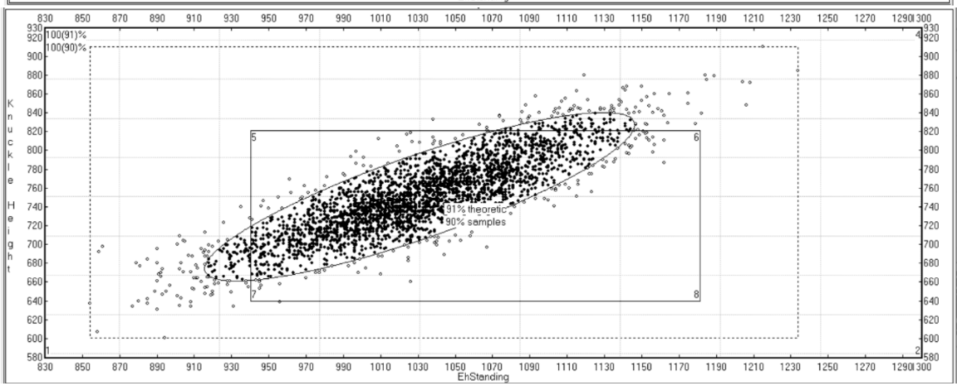


Table 8.3. Ideal manual handling of loads heights (mm)

Manual Handling Condition*	Population					
	Mixed		Female		Male	
	Inf. lim	Sup. lim	Inf. lim	Sup. lim	Inf. lim	Sup. lim
Acceptable high (between EhStand and ShStand)	1118.4	1278.8	105.3	122.1	112.3	132.0
Ideal (between KnuH and EhStand)	818.5	939.6	77.1	90.2	82.4	96.5
Acceptable low (between KH and KnuH)	563.7	680.1	52.4	65.6	56.7	69.9

When only summary tables are available with male and female data, the procedure is different. For a bivariate application (ideal manual handling heights) the female P5 of EHStand and P95 knuckle height of male population are used. In that case the results will cover a larger percentage (higher than 90%). Since raw data are not available to calculate the average or percentile of the mixed population, it is best to use the following equations to calculate the mean ($\bar{x}_T$) and standard deviations (S_T) when the size of the sample from female and male are not equal (example: KnuH dimension):

$$\bar{x}_T = \frac{n_m}{n_m + n_f} \times \bar{x}_m + \frac{n_f}{n_m + n_f} \times \bar{x}_f$$

Where a n_m (number of male) value of 2346 was considered, n_f (number of female) value of 600 and $\bar{x}_m$ (mean of male) was considered the KnuH dimensions, value of 758.8 (see table 8.1) and $\bar{x}_f$ (mean of female) value of 711.4.

$$\bar{x}_T = \frac{2346}{2346 + 600} \times 758.8 + \frac{600}{2346 + 600} \times 711.4$$

$$\bar{x}_T = 749.2$$

$$S_T = \sqrt{\frac{n_m}{n_m + n_f} \times S_m^2 + \frac{n_f}{n_m + n_f} \times S_f^2 + \frac{n_m \times n_f}{(n_m + n_f)^2} \times (\bar{x}_m - \bar{x}_f)^2}$$

Where a n_m (number of male) value of 2346 was considered, n_f (number of female) value of 600, S_m (Standard deviation of male) was considered the KnuH dimensions, value of 38.3 (see table 8.1) and S_m (Standard deviation of female) value of 34.8 and $\bar{x}_m$ (mean of male) was considered the KnuH dimensions, value of 758.8 (see table 1) and $\bar{x}_f$ (mean of female) value of 711.4.

$$S_T = \sqrt{\frac{2346}{2346+600} \times 38.3^2 + \frac{600}{2346+600} \times 34.8^2 + \frac{2346 \times 600}{(2346+600)^2} \times (758.8-711.4)^2}$$

$$S_T = 42.2$$

8.3.4. Practical implications in design and limitations

Alternatives using either a percentile/limits or bivariate procedures were used to successfully calculate the highest possible levels of match for the intended population. The bivariate approach was used, which is based on the use of percentiles, a widely used approach in research (Dianat et al., 2018). This approach considers the proper identification of critical dimensions for a particular design, since the use of bivariate approach makes the assumption that if the boundary cases are accommodated by the design, so are all of those between the ellipse (Robinette, 2012). Although using ellipses (bivariate) is very accurate and can ensure high levels of match, the entire raw data is needed for achieving those goals (Robinette, 2012). Another limitation of the bivariate approach occurs when the distribution of the data is highly scattered or for clothing design and other gear with multivariate dimensions. In those cases, using proper grading (Robinette, 2012) or scalability (Castellucci et al.,2015) are recommended. In the case of the current study, adding a 50 mm platform assured the desired match percentage of 90% without additional working height size or applying scalability.

Although having anthropometric data summarized in tables has been standard practice, it may be advisable to review it, since often data is presented separated exclusively for males and females. This may be useful for designing gender specific products, however it can be hard to design workplaces used by both genders, as the ones in the current study (Robinette, 2012). Including combined sample`s dimensions (male and female) should be standard practice when presenting anthropometric data, especially for those type of applications similar to the one shown in point 8.2.3.1.1, where not having the data combined makes the process more cumbersome, since the procedure for calculating match from a pre-established dimensional design ('reverse engineer'), will need to be executed separately for both males and females, thus knowing total match for an entire population gets more complex. In practice, match percentages for females and males can be calculated, but it is much better that anthropometric tables have mixed dimensions so that designers can be spared of first combining the data and /or calculating match percentages separated by gender.

The not adjustable values recommended in this study proved to match most of the population, where ISO dimensions accommodated none. Thus, the recommendations provided and their level of match when compared against ISO, account for the differences in the populations that were used to create the ISO Standard and highlights the importance of having specific population anthropometric data. Up to this date, there were no practical recommendations available regarding design of common industrial solutions for Chilean workers.

The recommendations present in the current study aimed to fill the existing gap in that area, since previous information was vague. Is important to mention that the research team presented their results in a simple and straight forward manner. This was done mainly because it is desired that designers aiming to solve/design most common issues (i.e. manual handling heights, production line heights and depth) have the information they need. This has been shown to be of extremely high value by previous research, mainly because industrial designers work on their own and rarely consult an ergonomist (Ranger et al., 2019). The same authors have also shown that industrial designers have a hard time to identify what anthropometric measurements are needed to size a product and that they would appreciate to have data according to geographical territory or a precise market. Moreover, industrial designers find standards more appealing and useful when they provide the dimensions "ready to use" sparing them of complex calculations

(Ranger et al., 2019). In that regard, the current paper provides the information in that format, aiming at designers and decision makers, in order to be used when designing for Chilean workers. The lack of specific and concrete applications of anthropometrics to design has been identified as a barrier for successful preventive recommendations and design (Dianat et al., 2018), therefore the current paper makes a contribution in that aspect.

Additionally, through an application example, a common scenario was addressed showing how to determine match percentage of a population, when only having a specific design dimensions and the anthropometric summary tables separated by gender. In those cases, the z-score allows to determine how many persons are matched, by indicating the percentile value where a design lays, thus indicating the levels of match. It is important to remember that percentile values considered for univariate methods (limits) only ensure match when the dimensions do not interact between them, such as the case of manual handling depths. In those cases, were interaction occurs or a univariate dimension is used as a 'two-way limit' (working heights per task type), the bivariate analysis proves to be useful. For ideal manual handling heights, a bivariate method was used with also depths, where the latter case does not have conflicting dimensions with heights, therefore a univariate 'one-way' limit approach, using the 5th percentile value of the shortest reach (female) can be selected with no issues. In those cases, where space, reach and other similar situations, the match % can be even greater, as it includes 90% of the females and more than 90% of the males.

The values regarding heights need to be corrected with shoe heights used by the intended user population as was presented in the current study. This approach is highly suggested since that way designers can customize production working and manual handling heights according to the specific garments used. This approach was taken further by (Guan et al., 2012) were they measured truck drivers with and without shoes, in order to quantify and typify the differences between the most commonly used shoes. Guan et al., (2012) also accounted for ethnic difference. In that regard, it is important to mention that the anthropometric dimensions that conducted to the recommended values presented on the current research were measured in 100 % Chilean born subjects. The first and only genetic national study found no differences in ethnicity in Chileans across the north , center and south of the country (Chilegenomico, 2015). This can be interpreted both as a strength and a weakness. A strength, since the survey was conducted in 2016, right before a massive migration of people from Haití arrived at the country, which are of African ethnicity (Rojas & Silva, 2016).Therefore data was gathered can be used as baseline to use without the ethnicity component. This can also be interpreted as a weakness, and even although at the moment most migrant workers do so in informal jobs in non-industrial sectors such as agriculture, fishing, services and construction (Díaz & Gálvez, 2015) they are not "anthropometrically" considered in the current recommendations, therefore future studies should account for ethnic differences or complement the current information with dimensions of the most representative groups of migrants, such as people from Venezuela, Colombia and Perú, whom recently have surpassed the Haitian community (INE, 2018).

Also, as suggested by Dianat et al. (2018) experimental trials with representative samples of users testing prototype versions of products/environments under controlled conditions seem to be necessary to evaluate the effectiveness of proposed designs. To consider this possibility, both objective (e.g. performance, time, error, etc.) and subjective assessments (e.g. user assessments such as preference, comfort/discomfort, usability, etc.) that provide valuable information about the design are recommended.

Before applying the anthropometric data it is important to considered the secular trend (H. I. Castellucci, Arezes, Molenbroek, & Viviani, 2015) and it is recommended to gather anthropometric dimensions at least every decade in order to account for secular trends experienced by populations due to improvements or worsening in the quality of life (Cole, 2000, 2003; Gordon & Bradtmiller, 2012; Tanner, 1986).

Finally, it is suggested that the recommendations made in the current study are tested using fitting trials with real users accounting also for preference, since theoretical match does not necessarily correlates with preference (Bahrampour, Nazari, Dianat, Asghari Jafarabadi, & Bazazan, 2019; Robinette, 2012).

8.4. Conclusion

The current research uses a recently published anthropometric database of Chilean workers to provide common industry design/preventive recommendations for that particular segment, and to show that the ISO not adjustable dimensions presented low levels of match when applied to the sample. Different matching methods were used, contributing to the generation of specific recommendation for working heights according to task type and safe manual handling heights/depths. Most of the applications, showed high levels of match (at least 90%) with just a couple of options. Ethnic differences should be considered in future studies together with the use of fitting trials considering preference to validate the recommendations presented in the current study.

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CHAPTER 9| Conclusions and future perspectives

9.1. Conclusions

This thesis has analysed Chilean workers' anthropometrics data regarding secular trend and its implications and applications in design of office seating and industrial settings. It has included 7 interrelated studies that were included in this thesis as separate chapters/papers.

As all the studies were organised as different papers, the corresponding conclusions were already presented for most of them. Therefore, this chapter is a compilation of the main conclusions obtained through the obtained data and the analyses that were carried out and presented at each chapter.

The aim of the first paper (chapter 2) was to determine though a literature review, whether the currently available peer reviewed studies in anthropometric of working adult populations in the field of ergonomics consider precision, reliability or accuracy issues during the collection of measurements. After the literature review it was noted that this topic was not thoroughly addressed, since none of the studies evaluated precision, reliability and accuracy. Only three studies evaluated precision, where the most used indicator was the MAD, used in two of these studies. Regarding the six papers that assessed reliability, four presented the recommended methods such as the ICC, R and CV which allow the identification of individual differences and systematic errors. Regarding the variables that may affect precision, reliability and accuracy, the majority of the papers reviewed presented great differences in terms of the measurement tools used. Furthermore, there is a clear lack of information regarding the training and procedures for anthropometric data collection.

Chapter 3 aimed to present the anthropometric dimensions of 2946 Chilean workers in order to support decisions regarding product design for that particular population. Additionally, the study compared the variations with other similar populations (Netherlands, USA, South Korea) that had the same variables present in their databases. This paper also reports the results of error testing methods during observer training and collection of anthropometric measurements. Male worker anthropometrics are significantly different from those of females, and the males presented larger values for all the dimensions except hip width. A significant difference between Chilean workers and their counterparts in the Netherlands, the US and South Korea was also found, and the results showed that Chileans were generally smaller than the first two populations and larger than the latter population, therefore the anthropometric tables presented in this article should be used by designers and manufacturers as a data source to either produce or select products for Chilean adult workers.

Chapter 4 was written with the aim of determining the differences in total body height and popliteal height in a cohort of male workers born in Chile between 1966 and 1996 in relation to their attained educational levels. A clear secular increase in body height and popliteal height was observed among Chilean male workers across all age cohorts. The overall secular increase can be attributed to improvement of living conditions in Chilean society, especially in younger workers, who have experienced the more recent benefits of improvements in Chilean society. When analysing the sample by educational level and age, the trends were only well-defined for workers with primary and secondary education in all age groups. The trend was increasingly diluted when looking at each successive younger and more highly educated group of workers. This finding probably has to do with the opening up of access to higher education since 1990, contributing to the dilution effect in height and popliteal height in the more educated and younger workers. The findings of this study could indicate that, in the case of Chile, educational level may no longer be associated with height or socioeconomic situation in adults with technical or university education, and thus other variables should be included to establish the socioeconomic background of subjects, not only educational level.

In order to address the changes in the anthropometric dimensions of Chilean female and male workers, Chapter 5 aimed at comparing the data gathered for the current PhD thesis in 2016 and the pre-existing data from 1995, accounting for the changes of more than two decades. The dimensions that showed the higher increase since 1995 were Weight and Stature. Weight increased more than Stature, which is coherent with the observed worldwide obesity trend. Women have experienced a Stature increase that doubled men`s Stature. This may be attributed to better living conditions, social programs and education access that addressed specifically women. Regarding other gender differences among Chilean workers, it was observed that male workers have larger measurement values than women, with the exception of Hip width, which is common on all populations. In addition to Stature, other anthropometric measures have also increased significantly during the last two decades, such as Popliteal height, Hip width, Buttock-popliteal length, Buttock-knee length, Shoulder height standing, Knuckle height, among others. Those segmental dimensions that experienced a greater increase are highly associated to seated design match, therefore common design such as the ones for public transport and office seating, should account for the increases observed in the current study.

As mentioned previously, a particular phenomenon was observed, where female average Height increases nearly doubled the one of males. This motivated the creation of Chapter 6, that aimed to analyse Height gender dimorphism across time in Chile based on four samples and to establish possible explanations for the differences using two dimensions (gender equality and general welfare indicators). The study found a reduction in the gap between female and male heights with time, that was correlated with a reduction in gender inequality across the different cohorts analysed. Improvements in women's reproductive health indicators, education and child mortality rate were found to be correlated with sexual dimorphism. A variation in mean height is a proxy for changing environmental conditions affecting growth and final height attainment. It seems that sexual height dimorphism can be used to complement the assessment of gender equality in a way that some well-being global indicators may not consider, highlighting more clearly gender inequalities or a reduction in them, as observed in the current section.

With the aim of applying different design equations using the anthropometric, Chapter 7 uses the data of Chilean workers in order to test the levels of mismatch of available standards (national and international) for three common sitting designs traditional seating with fixed desk and adjustable chair; traditional seating with adjustable chair and desk and hybrid seating with adjustable chair and desk. The office furniture dimensions considered in both standards (national and international) did not match the dimensions of the sample. Dynamic seating match, although highly beneficial for end users, proved to be the hardest configuration to obtain, mainly because the dimensions of the furniture (chairs) used did not matched entirely the Chilean workers' population. None of the chairs had a lift that could match most of the sample for traditional seating and perching. Two heights are suggested to match the majority of the sample higher trunk/thigh angles. In order to also perch, new equations were proposed, allowing designers to use higher saddle chairs or forward sloped chairs for accommodating a particular population, such as Chilean workers.

Chapter 8 uses the data of Chilean workers to provide the first ever design recommendations for two common ergonomics issues industrial settings, namely working heights in assembly lines according to task type (high visual/manual precision, moderate force and precision, high force) and ideal manual handling heights/depths. Comparisons were made also against international standards and match was assessed using univariate and bivariate methods. Examples and procedures were discussed, which are useful for designers since they allow to determine a population match percentage when only having summarized anthropometric data and the design in question.

It is also important to acknowledge some limitations of this work. In the case of Chapter 2, one considered limitation can be the search process itself, which may not have allowed the identification of all studies published worldwide. Additionally, the wide variety of research approaches adopted by the studies reviewed also made it difficult to summarize all the comparison data. The results from Chapters 3 to 8 are based in a very large sample of participants, however, this sample came from two specific regions of Chile, which may cause some bias. Finally, it is also important to note that the proposed designs in chapters 7 and 8 should be further tested in end users.

9.2. Perspectives for future work

The information from this thesis provided important findings for anthropometrics and its more common applications, such as product and workplace design, as well as less orthodox applications, such as its use for addressing variations in society`s inequalities or progress in similar dimensions. Based on the developed work, four main areas were identified as priority areas to develop further relevant research, namely:

- It will be necessary to consider error testing methods when training observers that conduct anthropometric surveys and to encourage researchers to report their error testing methods results. Such practice is applied very thoroughly in technical reports but not in peer review journals. The amount of space and effort needed to perform the previously stated recommendation is minor when compared to a full-size anthropometric survey, thus there is no reason why it should not become a common practice;
- Regarding data collection, other data of the subjects related to socioeconomic status should be also considered, such as educational level of the parents and

type of work performed by them. This could complement more accurately other research, such as the relationship of socioeconomic status with the subject's anthropometrics and its variations along time. In the case of Chile, future large-scale anthropometric surveys should account also for ethnic differences. The sample used in the current thesis was composed of 100% born Chileans, since it was taken previous to an unprecedented migration of people from Haiti, Colombia and Venezuela, who have an ethnic background that until 2016 was underrepresented in Chile, namely African heritage. It is suggested that in a decade when updating the anthropometrics of Chilean workers, to perform comparisons with the data of the current research in order to determine similarities and differences in the secular trend of the anthropometric dimensions with the ethnic factor in mind;

- Finally, other lines of research could point out to further test the equations used for seating and industrial applications using objective and subjective measures in laboratory settings, in order to assess the effects of those recommendations in end users regarding muscle activity, pressure distribution on feet/buttocks and preference. The creation or redesign of existing anthropometric database platforms, such as DINED, could be another line of research aiming it at non-expert users, in order for them to obtain a straight forward and simple calculation of a particular dimension when entering pre-set values, such as a country, ethnic characteristics, clothing used, product/dimension, user dimensions available, among others.

Appendix 1: Ethics Committee Approval

MUTUAL de seguridad

Santiago, 11 de Septiembre del 2015

Decisión del Comité de Ética Científico para Proyectos de Investigación

Título de la propuesta de investigación : Confección de base de datos antropométricos de la población trabajadora chilena, especificando las diferencias de género.

Fecha y lugar de la decisión : 11 de Septiembre del 2015, Mutual de Seguridad Santiago.

Nombre del investigador principal : Hector Ignacio Castellucci Irazoqui

Nombre del lugar de desarrollo de la investigación : Regiones de Santiago y Valparaíso

Decisión tomada: Se decide **APROBAR** el Proyecto de Investigación

Justificación de la decisión:

El investigador principal ha abordado adecuadamente los aspectos éticos relevantes para este tipo de estudios y ha realizado las modificaciones solicitadas por este comité. Una vez finalizado el mismo, se solicita enviar copia del informe final del proyecto de investigación así como informar de cualquier cambio o alternación del mismo, así como de los eventos adversos que puedan ocurrir en concordancia con las normas éticas nacionales e internacionales.

Adicionalmente, es imperativa la obtención de la autorización escrita del jefe o director del centro en donde se realizará la investigación, en concordancia con la Ley 20.120. Copia de esta carta debe ser enviada al CEC.

Esta resolución de aprobación tiene una duración de un año contada desde la fecha de emisión de la misma. Al término de dicho plazo, el investigador deberá enviar un informe de avance del mismo y solicitar, si así lo requiere, una extensión de la resolución de aprobación por el tiempo que reste para el término del proyecto.

Atentamente.

Leonardo Aguirre Aranibar
Secretario Académico
Comité de Ética Científico