3D anthropometric data collection for occupational ergonomics purposes: a review

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ABSTRACT: This paper presents a literature review of anthropometric data collection to address occupational ergonomics issues. One of the uses of anthropometry is to assess the negative effects associated with working postures. Using new techniques, such as 3D body scanners, it is possible to have very reliable data to use in the enhancement of workstation design or other ergonomic interventions, in order to prevent work-related musculoskeletal disorders.

1 INTRODUCTION

People spend most of their lives at work, therefore it is extremely important that the work environment is healthy, safe and comfortable in order to avoid occupational injuries and/or diseases. Optimising workplace design is also a central factor in insuring workers' efficiency and safety on the job. User-centered design approaches, where ergonomic principles and anthropometrics are considered, should be preferred (Wichansky, 2000). This type of design aims to minimize the stress imposed on the users and to eliminate harmful postures. When their workplaces are inadequate users may experience work-related musculoskeletal disorders (WRMSD). Workers' WRMSD are very prejudicial for companies since they are one of the major causes of reduced work capacity, absenteeism or productivity losses (Escorpizo, 2008). Hence, user-friendly workplaces are decisive in workers' welfare. In order to design this type of work environment, it is essential to have a full understanding of the human body and to create workplaces which are suitable for users taking into consideration different body dimensions and different activity requirements.

Anthropometry is the branch of the human sciences that deals with body measurements, such as size, shape, strength and working capacity (Pheasant, 2006). When applied in occupational studies the data acquired (anthropometric measurements) can be used to assess the interaction of workers with their tasks, tools, machines, vehicles, and personal protective equipment (PPE). This last issue, PPE, is very important especially in regard to determining the degree of protection afforded against hazardous exposures. An inadequate fit of the personal protective equipment does not provide workers with sufficient protection from health and injury exposures, such in the case of facemasks or hearing protection devices (Hsiao & Halperin, 1998). Thus, it is extremely important that the designs are compatible with normal anthropometric measurements of a workforce, since misfit could result in undesired incidents.

However, currently the amount of data on the size and shape of industrial workers is limited. Most of the data used by safety and ergonomics researchers are based on data drawn from studies of military personnel that are quite different from the average workforce populations. As anthropometric characteristics vary according to several factors (e.g. gender, age and race), creating anthropometric databases that reflect the full variation of the population typically requires considerable resources (time, know-how, funds, equipment and workforce, etc.). Nevertheless, nowadays, there are a growing number of anthropometric databases attempting to represent the characteristics of entire populations (Barroso et al., 2005). However, as the study of Hsiao et al. (2002) concluded, there are even significant anthropometric differences among occupational groups, meaning that, for example, a truck driver and a firefighter are, or can be, anthropometrically different from each other and from the average civilian population.

One of the many applications of anthropometry for occupational ergonomics is the assessment of the body modifications that are associated with different working postures (sitting and standing). This paper aims to present a literature review with the identification of the negative effects underlying each working posture, as well as investigating the literature on studies designed to determine if they contribute to the appearance of WRMSD, and also present some ergonomic interventions that are designed to reduce their magnitude.

2 COLLECTION OF ANTHROPOMETRIC DATA

The variance in body dimensions is frequently reported by calculating means, standard deviations, and percentiles (Roebuck et al., 1975). Despite being useful to create general and broad parameters for the design of workplaces and products, detailed fit information was missing for use in cases such as personal protective equipment. Until the development of 3D body scan technology anthropometric studies were conducted by manually measuring each study participant using tools such as anthropometers, calipers, and tape measures. 3D body scanners have revolutionized anthropometric data acquisition, being more practical, accurate, fast and, comparably, less expensive. There are several types of imaging techniques to create full body images. These imaging technologies, include 2D video silhouette images converted to 3D models, white light phase based image capture, laser-based image capture, and radio-wave linear array image capture (Treleaven & Wells, 2007; Istook & Hwang, 2001). Body scanning systems normally consist of one or more light sources, one or more vision or capturing devices, software, computer systems and monitor screens to visualize the data capture process (Daanen & Water, 1998). In most cases, the 3D body scanner captures the outside surface of the human body by using optical techniques. This means that there is no longer the need for physical contact with the subject's body, but the image based data collection introduces the question of privacy. There are different opinions regarding the privacy of the body scanner. If in the one hand it provides more privacy, since it avoids the need to actually touch the body, on the other hand the highly accurate more personal images produced by the scanners are potentially more invasive since they can be stored insecurely and transferred directly from the scanner over local networks or the internet. Nevertheless, with these advances in anthropometric science and computer-based human-form modeling it is now possible to give a different perspective to the collection of anthropometric measurements.

2.1 *Body variations due to working posture*

As can be imagined, the shape and size of the human body can be affected by repetitive physical activities performed during a working period. Moreover, the body may also be influenced by the working posture adopted during a workday, i.e. when people spend most of their time sitting or standing. The following considerations reflect the effects on the human body of excessive sitting and excessive standing.

2.2 *Excessive sitting*

There are many people who spend approximately 8 to 9h of their day in a sedentary behavior and a large part of this sedentary time is spent at work (Healy et al., 2011). Some studies demonstrated that most working adults spend 1/2 to 2/3 of their time at work in a sitting position (Tigbe et al., 2011). In some jobs the time spent on sedentary behavior can reach 90%, such as the case of call centers, reported in Toomingas et al. (2012). Undoubtedly, sedentary behavior is directly related to obesity (Pi-Sunyer, 1999). Moreover, sedentary behavior has been shown to be an independent risk factor for obesity, diabetes, some cancers and death from any cause (Katzmarzyk et al., 2009). An effect of prolonged sitting that has been very much analyzed is leg swelling (Table 1).

Table 1. Effects of prolonged sitting.

Author	Identified effects
Pottier et al., 1969	Volume increase causes: hydrostatic pressure, thermal increase and obstruction of blood circulation.
Shvartz et al., 1982	Chair's seat compresses the veins in the thigh and hip areas, causing poor blood circulation to the legs.
Seo et al., 1996	Higher lower leg swelling due to the activity level required to the leg muscles to sustain the body.
Winkel & Jorgensen, 1998	Swelling and discomfort of the lower extremities.
Carpentier et al., 2004	Venous disorders and vascular effects

However, sitting may be less energy consuming than standing and less stressful on the lower extremity joints (Grandjean, 1988). Nevertheless, several authors refer the increased risk of low back pain in seated jobs (Kroemer & Robinette, 1969) and the greater disc pressure for a seated posture than for a standing posture (Andersson et al., 1979). Lehman et al. (2001) conclude that working in a seated position can also require greater shoulder abduction, which causes more stress on the shoulder joints and shoulder/neck. Many health specialists, such as orthopedists and physical therapists assume that deconditioning of the trunk and lumbar spine structures occur due to long-term sitting without longer active periods of standing, walking or running (Mörl & Bradl, 2013). The same authors affirm that this deconditioning may be a reason for low back pain and for the accelerated degeneration of lumbar spine structures. Due to all these adverse effects, some authors suggest that it is important to combat occupational sedentariness, by rethinking, and redesigning the way people work (McCrady & Levine, 2009). Mörl and Bradl (2013) stated that to reduce the high prevalence of low back pain in sedentary work, reasonable prevention is necessary. While seated, the lumber muscles have low activation rates, so it is possible to conclude that the use of special office chairs to protect the spine or to train the paravertebral muscles will fail since the muscle activation depends more on the task than on the office chair used (van Dieën et al., 2001). Thus, some researchers conclude that the only way to prevent adverse effects is to increase physical activity in the workplace, promoting postural changes. Still, it is difficult to define with precision the amount of time that should be spent on each working posture since the optimal proportion of standing to sitting is unknown (Messing et al., 2008).

2.3 *Excessive standing*

There are still many professions, such as retail workers, cleaners, security guards, supermarket checkout employees, quality control and assembly workers, and health care staff that require workers to adopt a standing posture during the whole work day (Bahk et al., 2012). According to Balasubramanian et al. (2009), the standing posture can be divided in dynamic standing (in which a worker intermittently walks while on the job) and stationary standing (in which a worker does not walk, but stands still, while on duty). Most industrial jobs are characterized by a stationary standing posture, however, the dynamic ergonomic posture is not universally employed (Messing & Kilbom, 2001). Depending on the job, a standing posture provides a more stable condition for the low back by preserving the natural lordosis of the lumbar spine (Andersson, 1979). Standing also allows for dynamic use of the arms and trunk, which is better for handling loads, and enables workers to cover larger workspace areas because of the ability to move (Lehman et al., 2001). According to Bridger (1995), standing work is better than sitting work since the reach is greater, the body weight can be used to apply forces, requires less space for the legs, the lumbar disk pressure is lower and it can be maintained with little muscular activity. The investigation carried out by Balasubramanian et al. (2009) showed that during 1h of mechanical assembling operations, the subjects demonstrated the appearance of fatigue in lower extremity muscles at a much faster rate in stationary standing than in dynamic standing. The same authors indicated that along with the fatigue the perceived pain and discomfort in the lower extremity muscles was also relatively high during the stationary standing. Other authors refer different effects of the prolonged stationary standing posture, such as the ones presented in Table 2. One of the most studied effects of prolonged standing postures is the appearance of varicose veins and leg cramps. Several studies demonstrated that the risk for varicose veins is associated with different aspects, e.g. age, female gender, family history, pregnancy, obesity and prolonged standing or sitting (Beebe et al., 2005; Ahti et al., 2010). In the work of Bahk et al. (2012), it has been shown that women had a higher prevalence of varicose veins and nocturnal leg cramps than men. However, the occupational characteristics of the job could be more predictive of the prevalence of varicose veins than gender itself. Concerning nocturnal leg cramps, the same study showed that women had higher prevalence of leg cramps than men, regardless of their work posture.

Table 2. Effects of prolonged stationary standing.

Author	Identified effects
Hansen et al., 1998	Chronic venous insufficiency, leg swelling, discomfort and tiredness
Dempsey, 1998	muscle fatigue aggravation, neck and shoulder stiffness
Krause et al., 2000	Progression of carotid atherosclerosis
Cham & Redfern, 2001	Lower extremity discomfort
Messing et al., 2008	Lower extremity discomfort fatigue and swelling; low back pain, and entire body fatigue
Ngomo et al., 2008	Orthostatic intolerance
Tissot et al., 2009	Musculoskeletal disorders in the back
Bahk et al., 2012	Higher prevalence of varicose veins and nocturnal leg cramps.

3 DISCUSSION

Many of the effects mentioned before, such as foot and leg swelling, reduced circulation, varicose veins, and lower extremity discomfort are associated with both prolonged sitting and prolonged standing (Sadick, 1992). As such, it is important to note that a posture that causes pain or discomfort is generally harmful for workers since it can lead to WRMSDS. These disorders will reduce the working capacity and consequently cause productivity losses and can lead to work disability (Escorpizo, 2008). King (2002) stated that the effects of musculoskeletal disorders were associated with absenteeism, lack of productivity and decreased well-being. It is possible to conduct a study of the variance in anthropometric measurements to assess if the workplace, as well as the working postures adopted, are contributing to the development of WRMSD. In these cases the use of 3D anthropometric data allows the study to be more effective since, when compared to the traditional anthropometry methods it has many advantages. Traditional anthropometry uses devices such as calipers and tapes to determine the dimensions of the human body. According to Pargas et al. (1997), apart from being tedious, inconsistent and inaccurate, when the manual measurement procedure is made by different people it might have several variations: compaction of flesh during measurement, inconsistent landmarking (palpating for specific points generally located at bone prominences) and tension of the measuring tape. Even if measurements are taken by the same person it is possible to have lack of consistency throughout the day when that person gets tired (Pargas et al., 1997). With the 3D body scanners capturing the body dimensions is fast and can be reproduced almost exactly the same way all the time. One of the most important benefits of this type of measuring procedure is that the data of the subjects can be stored and accessed when necessary (Daanen & Water, 1998). Furthermore, the number of anthropometric variables that can be derived from a scanned human body is almost without limits. Nevertheless, Daanen and Water (1998) pointed out some disadvantages of 3D-scanning compared to traditional anthropometry, e.g., the initial investment on a body scanner, camera blocking effects in arm pits and crotch, light absorption by the hair and skin, moving artifacts and reliable data processing and handling.

Once problems are identified it is very important to act in order to prevent poor working conditions. This can be accomplished by implementing ergonomic interventions. There are many cases where the ergonomic interventions used during prolonged standing tasks reduced, but did not eliminate completely, the risk of WRMSD (Hasegawa et al., 2001; Messing & Kilbom, 2001; Chiu & Wang, 2007). Using sit/stand chairs or workstations, wearing soft shoes, using shoe insoles, wearing compression stockings, using foot rests, standing on soft surfaces or standing on floor mats are examples of improvements to the work environment that can be made to reduce leg swelling, discomfort and fatigue in the lower extremities (Hansen et al., 1998; Madeleine et al., 1998; Chester et al., 2002; King, 2002). Even though sit/stand chairs are a popular solution, their use might not be very effective, as shown in the work of Chester et al. (2002) demonstrated where using sit/stand chairs caused the most swelling (when compared to standing and sitting postures). Also, some publications showed that implementing sit/stand workstations in an office environment leads to lower levels of whole body discomfort without resulting in a significant increase in performance (Karakolis & Callaghan, 2013; Davis et al., 2009). Several publications showed that the floor type likely plays an important role in discomfort while standing. Many workplaces have installed soft floors or floor mats in order to reduce the leg muscle discomfort during prolonged standing (Madeleine et al., 1998). Lin et al. (2012) discovered that subjective discomfort ratings were related to floor type, shoe condition, and standing time. Making various proscribed leg movements (Lin et al., 2012), having frequent sitting breaks and including an optional seat or a footrest increases the variety of body positions available for a worker and encourages frequent changes between them, resulting in less discomfort and swelling in their lower extremities (Sartika & Dawal, 2010). The work from Winkel and Jorgensen (1998) demonstrated that leg and foot activity reduces swelling and increases the blood circulation. Thus, a static work posture, whether it is standing or sitting is discouraged since changes in work posture are important in reducing fatigue (Kroemer & Robinette, 1969). The study of Hansen et al. (1998) showed that standing work without any motion or walking caused greater musculoskeletal discomfort than a combination of standing or walking tasks. Considering the differences between and similarities of the two postures, the choice must reflect the requirements of the tasks to be performed. At the same time ergonomic design should be considered since it might reduce the risk of acquiring lower extremity disorders and may have a positive impact on productivity enhancement (Balasubramanian et al., 2009).

4 CONCLUSIONS

As workers' productivity and well-being relies on working conditions, evaluating the negative effects caused by the work postures assumes a very important role. Working postures that are 'wrong' (or extreme) or that are adopted for long periods of time may result in WRMSD. These disorders may put at risk companies' competitiveness since they areand absenteeism. Accordingly, knowledge about the adverse effects of different working postures is essential. As such, being able to determine the anthropometric changes related to each work posture is one of the new concerns of anthropometry applied to occupational ergonomics. To do so, it is now possible to use new measuring techniques, such as the case of 3D anthropometry data by using 3D scannersas a more efficient and rapid data collection method than traditional anthropometry.

The authors of this paper are already involved in a research project, as part of a PhD project that is based on this identified need, i.e. the need to understand the implications of the working posture for the workers' anthropometrics. In this project, aspects that are being considered are: the determination of the modifications in the human body that occur with each posture (as well as understanding how quickly they happen) or identifying the anthropometric changes that can be more harmful for the workers. And last but not the least, determining the percentage of time that should be spent in each posture for the greatest health and productivity outcomes.

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