

MOSAIC (Multivariate Occupation-Specific Anthropometric) Database: Improving Inclusive Design by Accommodating for Anthropometric Differences

Amin Yazdani & Marcus Yung

¹Canadian Institute for Safety, Wellness, & Performance

SUMMARY

The design of work products, including personal protective equipment (PPE), tools, equipment, and assistive technologies, play a significant role in their function, usability, adoption, and ultimately their effectiveness in preventing injuries in workplaces. Unfortunately, work product manufacturers and designers often rely on dated, general population anthropometric data sets. This presentation will describe through two studies the current challenges with work product design, particularly PPE, and detail how MOSAIC will support the inclusive design of work products to accommodate Canada's diverse workforce.

KEYWORDS

Product Design, Usability, Personal Protective Equipment

Introduction

Poor anthropometric accommodation, leading to ill-fitting work products including personal protective equipment (PPE), tools, equipment, and assistive technologies, may prevent them from functioning optimally. Poor function may result in physiological and biomechanical burdens on workers, increase risk of workplace injury and performance deficits, create a safety hazard, and discourage its adoption and use (Anderson et al., 2017; Hsiao et al., 2014; Robertson et al., 2020). The increased risk of injury has promulgated into a new regulatory requirement for construction sites in Ontario, Canada (O. Reg. 61/23), which requires all businesses to consider all body types and ensure properly fitted PPE.

From a semi-structured interview with manufacturing and designers of work products, they have intimated to us that they do not have access to updated and relevant anthropometric databases representative of Canada's large social and cultural mosaic. First, the few existing available databases are based on body shape scans and body dimensions of general populations from the United States of America, the Netherlands, and Italy (Robinette et al., 1999). Second, there is evidence that different occupational groups have distinctive anthropometric characteristics from the general population, and therefore general population anthropometric data may not be suitable when designing products for workers and their jobs. For instance, compared to the general U.S. population, U.S. male firefighters are heavier and have larger chest and waist circumferences and U.S. female firefighters are taller and have larger physiques (Hsiao et al., 2002). Third, general population anthropometric data are often based on static poses (standardized A and T poses); however, body dimensions and surface shapes change during human body movement and may affect fit and comfortability of PPE (Kang & Kim, 2023). In a study that tracked changes of body

shapes and dimensions during dynamic movement, height dimensions significantly changed during walking, shoulder and chest lengths were affected by arm movement, and chest and waist circumferences were affected by movement of the trunk (Kang & Kim, 2023).

Canada's MOSAIC (Multivariate Occupation-Specific Anthropometric) is a current research initiative that focuses on the development of the necessary anthropometric databases to ensure work products are inclusively designed to accommodate Canada's diverse workforce. The MOSAIC database will be comprised of the relevant body dimensions that enable product designers to establish design parameters of their products, such as its dimensions/geometry, its adjustment ranges, and accommodation envelope (da Silva et al., 2010). MOSAIC focuses on meaningful and representative models of human variation, developed from multivariate accommodation approaches, which consider multiple body dimensions, simultaneously, providing better accuracy in estimating and defining anthropometric accommodation (da Silva et al., 2010).

In this presentation, two studies will be provided for context on the importance of new anthropometric datasets for work product design. The MOSAIC initiative will then be described, including the methodology for the extensive anthropometric survey, and our future plans for this critical initiative.

Methodology and Findings

Study 1: State of the Art Knowledge in Workers' Experiences with Personal Protective Equipment

Given the significant influence of PPE on worker health, wellbeing, and productivity at work, several reviews have investigated workers' experiences with PPE. In the context of skilled work, reviews primarily examined reasons for non-compliance (Jalil Al-Bayati et al., 2023), PPE performance (Brisbine et al., 2022), or are limited to worker experiences with specific PPE such as work boots (Dobson et al., 2017) or eye protection (Atalay et al., 2024). Unfortunately, the reviews largely neglected the lived experiences of PPE users, including comfort, identity expression, and cultural relevance. Therefore, the objective of this systematic review (Tennant et al., 2026) was to synthesize the current state of the literature on worker priorities, expectations, and experiences with PPE in the skilled trades using the Functional-Expressive-Aesthetic (FEA) model. FEA is a consumer needs model of apparel design, previously applied to PPE, that considers fit and comfort, identity expression, and cultural relevance (Lamb & Kallal, 1992; An et al., 2023).

Thirty-two peer-reviewed studies were identified through a systematic search of four electronic databases, screened using PRISMA guidelines, and appraised using the Mixed Methods Appraisal Tool. Workers across diverse trades, ages, genders, and geographies consistently reported challenges with PPE fit, comfort, and functionality. Full FEA needs were rarely met for either men or women; women reported facing disproportionate barriers accessing appropriate PPE, including poor fit and limited access to gender-appropriate designs. Expressive and aesthetic dimensions of PPE also influenced women's self-efficacy and workplace belonging. Systemic factors such as employer practices, industry limitations, and regulatory oversight further shaped worker experiences with PPE. Despite legislative mandates for appropriate PPE provision, gaps persist in accessibility and adherence.

This review highlighted the need for inclusive design; targeted research on marginalized populations including those with non-male identities, older workers, and newcomers to Canada; as well as multi-level interventions to improve equitable access to PPE that meets the needs of all workers in the skilled trades workforce.

Study 2: Understanding the Unique Perspectives and Lived Experiences of Equity Deserving Groups in the Skilled Trades

Semi-structured interviews were conducted with current and future (i.e., trainees and apprentices) skilled tradespeople from equity deserving groups (e.g., non-male identities, aging workforce, and persons with disabilities). These interviews helped us understand the perspectives of a diverse workforce, the barriers and facilitators of PPE usage and adoption, and their user requirements for effective and inclusive design. Interviews consisted of probing open-ended questions, were audio recorded, and data were analysed using thematic analysis.

From 26 interviews of participants who identify as “non-male”, we found three emerging themes: (1) Fits are not appropriate for non-male bodies across many/ most PPE types, (2) Non-male workers are often expected to use generic sizing provided or buy their own, and (3) PPE that does not fit well has led to safety concerns on worksites. From 22 interviews with workers who have more than 20 years of work experience and/or 55+ years of age, we found three emerging themes: (1) Issues with form, fit, and function appear to be less common in this group, (2) Participants have rarely reported concerns with their PPE to employers or manufacturers – they generally seem to use what was provided, and (3) PPE had improved over the course of their career, especially in relation to comfort and availability. From 31 interviews with persons with disabilities, we found three emerging themes: (1) PPE that were uncomfortable or fit poorly were often overstimulating and/or presented a distraction, (2) Occasionally participants reported that disabilities that impacted learning or memory resulted in forgetting to wear PPE, and (3) Several participants had ideas or suggestions related to how to improve the fit and function of PPE for their disability.

Study findings indicate significant barriers in effective use of PPE, mainly due to their existing fit and design. The inadequate sizing poses a significant unintentional safety hazard, which may contribute to slip, trips, and falls, caught by incidents, or injuries due to distractions. Inadequate sizing may also contribute to increased musculoskeletal disorder risks, where excessively large products reduce tactile sensitivity and dexterity, while excessively tight/small products inhibit blood flow and possibly nerve damage. Ultimately, interview participants intimated that inadequately sized PPE inhibits their sustainable use, increasing their risk of injury, accidents, and fatality in the workplace.

MOSAIC Initiative and Key Takeaways

The two studies exemplify the importance of new job-specific anthropometric databases for better inclusively designed work products. MOSAIC is timely as workplace injuries and disabilities continue to be significantly high in Ontario, where construction workers are up to 50% higher risk for sustaining a musculoskeletal disorder (MSD) than the general working population (Schneider, 2001). Women in the skilled trades are particularly vulnerable to injury and disability, upwards of 2 to 4 times the probability of sustaining a workplace injury compared to their male counterparts (Messing et al., 2022). The current skilled trades workforce is also rapidly aging; 22% of the total construction workforce is over 50 years of age (Statistics Canada, 2020). Older workers are at an increased risk of disabling injury, having diminished physical and sensory capabilities (Sokas et al., 2019; Schwatka et al., 2012), and require longer recovery time compared to younger workers. Older workers are at a high risk of experiencing recurring injury (Schwatka et al., 2012). Through this research, supporting the design and development of inclusively designed exoskeletons and PPE will help reduce injury risks within these vulnerable populations, promote occupational health equity so that the entire diverse workforce can benefit from assistive technologies and PPE, improve job accessibility, and prolong the healthy working life of the broader skilled trades workforce.

MOSAIC represents one of the world’s only job-specific anthropometric database based on the body dimensions of the current and emerging workforce. Between 2025 and 2028, extensive anthropometric surveys will be conducted on work sites and at training centres, enabled by mobile laboratories, with thousands of construction and paramedic workers, from across Ontario, Canada.

Since the launch of the initiative, in a 6-month span, over 500 individuals from Ontario's construction and first responder workforces have been collected from diverse geographic regions. Beyond 2028, MOSAIC will expand to include other key sectors and industries including healthcare, agriculture, energy, forestry, manufacturing, and service.

The large anthropometric survey leverages an in-lab and field-based state-of-the-art 4D photogrammetric body scanning technology systems (Figure 1a and b; Move 4D, Instituto de Biomecánica de Valencia), which generates avatars and digital human models, to calculate and track over 165 precise body dimensions, areas, and volumes during static poses and 19 body dimensions during dynamic movements. These photogrammetric systems have demonstrated high validity and reliability (De Rosario et al., 2023). Whole-body photogrammetric systems are complemented by a portable photogrammetric 3D foot scanner (DOMEScan, Instituto de Biomecánica de Valencia), capable of extracting 25 dimensions relevant to orthotic and footwear design, an in-house developed optical 3D hand scanner, and body composition measurement systems for estimates of the amount and distribution of fat, muscle, and water (380, InBody). MOSAIC will also capture workers' muscular strength (i.e., grip, lower body, upper body; DynaMo Plus and Max, VALD) to better understand how work and the work environment can optimally match the capabilities of workers. A self-reported survey will gather insights into participant demographics, occupational task exposures and demands, tool and equipment use, and their perceptions of PPE fit and comfort.

Figure 1: (A) In-lab version of the 4D anthropometric photogrammetry system and (B) Custom field-based 4D anthropometric photogrammetry system.

Body scans will be processed based on standardized procedures and anthropometric data will be analyzed and compiled into a database according to ISO Standards (2012, 2015) for univariate (Figure 2) and multivariate (Figure 3) data. Analytical toolboxes will be developed based on population demographics. MOSAIC will also allow researchers to address emerging research questions, including the anthropometric differences underlying perceived fit issues with PPE.

Figure 2: Example of database interface based on univariate anthropometric data. Users will be able to access univariate data (descriptive statistics including mean and percentiles) based on population of interest (i.e., sector, occupation, and demographics), measurement parameter (i.e., body dimension, composition, strength), and variable (i.e., body segment length, area, volume).

Figure 3: Example of database interface based on multivariate anthropometric data. Users will be able to interface with a statistical shape model for advanced biomechanical and design simulations for specific populations of interest (i.e., sector, occupation, and demographics).

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