Applied Ergonomics 51 (2015) 137–151

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Seat and seatbelt accommodation in fire apparatus: Anthropometric aspects

Hongwei Hsiao [a, *], Jennifer Whitestone [b], Michael Wilbur [c], J. Roger Lackore [d], J. Gordon Routley [e]

[a] National Institute for Occupational Safety and Health (NIOSH), Morgantown, WV, USA
[b] Total Contact Inc., Germantown, OH, USA
[c] Emergency Vehicle Response, Otisville, NY, USA
[d] Fire Apparatus Manufacturers Association, Lynnfield, MA, USA
[e] International Association of Fire Chiefs, Fairfax, VA, USA

ARTICLE INFO

Article history:
Received 16 September 2014
Accepted 11 April 2015
Available online 21 May 2015

Keywords:
Firefighter
Seatbelt
Anthropometry

ABSTRACT

This study developed anthropometric information on U.S. firefighters to guide fire-apparatus seat and seatbelt designs and future standards development. A stratified sample of 863 male and 88 female firefighters across the U.S. participated in the study. The study results suggested 498 mm in width, 404 mm in depth, and 365–476 mm in height for seat pans; 429–522 mm in width and 542 mm in height for seat back; 871 mm in height for head support; a seat space of 733 mm at shoulder and 678 mm at hip; and a knee/leg clearance of 909 mm in fire truck cab. Also, 1520 mm of lap belt web effective length and 2828 mm of lap-and-shoulder belt web effective length were suggested. These data for fire-truck seats and seatbelts provide a foundation for fire apparatus manufacturers and standards committees to improve firefighter seat designs and seatbelt usage compliance.

Published by Elsevier Ltd.

1. Introduction

1.1. Seatbelt use influences firefighter safety

There are approximately 1.1 million firefighters in the United States (Karter and Stein, 2011) and vehicle-related incidents are the second leading cause of firefighter line-of-duty fatalities (Karter and Molis, 2013). During the 10-year period from 1998 to 2007, 148 firefighters were killed in 133 road vehicle incidents (Fahy, 2008). Also, in 2011 alone, 14,850 fire department emergency vehicle collisions occurred, resulting in 970 firefighter injuries, while fire departments were delivering emergency services (Karter and Molis, 2012). Lack of seatbelt use was identified as a significant contributing factor to these deaths and injuries. Of the 406 firefighter deaths while responding to fires and returning to stations during 1977–2006, seventy-six percent were not belted (Routley, 2006).

While seatbelt noncompliance is sometimes attributed to departmental culture or inherent risk-taking personalities of firefighters (Siarnicki, 2011), it has been demonstrated that some firefighters are not physically able to easily buckle their seatbelt when encumbered with turnout gear and firefighting equipment. A NIOSH (National Institute for Occupational Safety and Health) Fire Fighter Fatality Investigation and Prevention Program review report noted that a quarter of fire departments indicated that their firefighters were not able to fit comfortably in their seatbelts while wearing turnout gear in emergency vehicles (Peterson et al., 2009). Also, unpublished data from this study found that 38% of female and 48% of male firefighters had problems with seatbelt use in their fire trucks (NIOSH, 2012).

Adequate seatbelt use and seat configuration have proven efficacy in reducing the likelihood of injury in fire-truck collisions (Campbell, 1999; NIOSH, 2005). The difficulty experienced by some firefighters in fastening their seatbelts was due to trade-offs in the design of both the seat and seatbelt systems. Many of these firefighters experienced difficulty in reaching their seatbelts because seat spacing was too narrow and confining. For others, the belt length was too short and occupants were unable to buckle their belt

* Corresponding author. National Institute for Occupational Safety and Health, 1095 Willowdale Road, Morgantown, WV 26505, USA.
E-mail address: hxh4@cdc.gov (H. Hsiao).

http://dx.doi.org/10.1016/j.apergo.2015.04.004
0003-6870/Published by Elsevier Ltd.

without first removing their jacket or their personal protective equipment.

1.2. History of fire apparatus seat and seatbelt standards

Fire truck seat and seatbelt designs are addressed in the National Fire Protection Association (NFPA) 1901 Standard for Automotive Fire Apparatus and 1906 Standard for Wildland Fire Apparatus. In 1991, NFPA apparatus standards specified that all firefighters riding on an apparatus must be inside a completely enclosed cab equipped with an approved seatbelt for each occupant (Peters, 2014; NFPA, 2008). A sign stating "Occupants must be seated and belted when apparatus is in motion" needed to be visible from each seating position. Also at that time the standards established seat unit space of 560 mm at the shoulder level, seat pan width of 460 mm at hip level, and seat pan depth of 380 mm.

Beginning in 1999, the NFPA added further requirements for seatbelt design, stating that each crew riding position must be provided with a seatbelt, that forward-facing seats adjacent to a side wall must be provided with a lap-and-shoulder belt, and that the seatbelt must be "designed to accommodate a person with and without heavy clothing" (NFPA, 2003). Fire apparatus manufactured during this period were not required to meet any special seatbelt length other than what was mandated by the Federal Motor Vehicle Safety Standards (FMVSS 209; U.S. Department of Transportation, 2013a) which stated that the seat belt adjustment must accommodate a 5th percentile adult female (46.3 kg weight and 599 mm waist circumference) up to a 95th percentile adult male (97.5 kg weight and 1080 mm waist circumference). These percentile values were based on the military MIL-STD-1472 data and standards (U.S. Department of Defense, 2012).

While these seat and seatbelt specifications for fire apparatus did evolve to include some consideration for the bulk and encumbrance created by firefighting clothing, there were no specific dimensional values to guide the seat, seatbelt, or apparatus manufacturer. In 2006, the National Fallen Firefighters Foundation (NFFF), International Association of Fire Chiefs (IAFC), International Association of Fire Fighters (IAFF), Safety Task Force of the NFPA 1901 Fire Apparatus Standards Committee, and Fire Apparatus Manufacturers' Association (FAMA) jointly advocated for an anthropometric study of U.S. firefighters to update dimensional specifications on fire apparatus seats and seatbelts. NIOSH began a research review process of the subject in 2007 and initiated the national firefighter anthropometry study in 2008 (Hsiao, 2008).

The updated 2009 edition NFPA1901 Standard for Automotive Fire Apparatus (NFPA, 2008) retained the same specifications for seats dimensions as those that appear in the 2003 edition (NFPA, 2003). The 2009 standard adopted study data available from a pilot study of firefighter anthropometry (NIST, 2008) and a white paper from fire apparatus manufacturers on firefighter anthropometry (FAMA, 2007) for its seatbelt specification development. The 2009 standard also adopted a sizing procedure for the development of seatbelt specifications that was proposed in 2007 for this current project (Hsiao, 2008). The 2009 edition specified that seatbelt web length shall be a minimum of 2800 mm for Type II belts (pelvic and upper torso restraint) and a minimum of 1525 mm for Type I belts (pelvic restraint).

1.3. Relation to other standards

Firefighters wear equipment and clothing that weigh, on the average, 11.9 kg for men and 10.5 kg for women (Hsiao et al., 2014). The seats and seatbelt systems designed for general purpose would not accommodate firefighters well. In addition, seats and seatbelt systems designed and sized for the military (i.e., MIL-STD-1472) and for the general population (i.e., FMVSS) may not provide the same level of fit for firefighters because the designs do not reflect the greater body size exhibited by the firefighter population (Hsiao et al., 2002). For instance, the 5th percentile female firefighter weighs 56.6 kg with a waist circumference of 732 mm. By comparison, according to MIL-STD-1472 and FMVSS, the 5th percentile female weighs 46.3 kg and has a waist circumference of 599 mm. Similarly, the 95th percentile male firefighter weighs 120 kg with a waist circumference of 1165 mm. By contrast, according to MIL-STD-1472 and FMVSS, the 95th percentile male weighs 97.5 kg with a waist circumference of 1080 mm (Hsiao et al., 2014). Now that the NIOSH national firefighter anthropometry study has been completed, there are sufficient data to systematically evaluate the current design specifications of seats and seatbelts.

2. Objectives

This paper evaluated current NFPA specifications of fire-apparatus seats and seatbelts using data obtained through the NIOSH national firefighter anthropometry study and proposed modifications to the specifications. Specifically, this study assessed the following NFPA seat and seatbelt standards and provided data which standards developers can use to evaluate seating and seatbelt minimum standards to accommodate the current U.S. firefighter population:

The NFPA 1901 standard specifies a minimum of 460 mm in seat pan width and 380 mm in seat cushion depth (Fig. 1a), a minimum of 460 mm in width for seat backrest at the base, a minimum of 460 mm vertical backrest support, and a minimum width of 560 mm at the shoulder level as a seat unit space (Fig. 1b).

The NFPA 1901 standard requires Type II (3-point) belts (Fig. 1c) for forward-facing outboard seating positions; Type I belts (lap belts) were acceptable for all other seats, including tiller cabs. The standard specifies that seatbelt web length shall be a minimum of 2800 mm for Type II belts and a minimum of 1525 mm for Type I belts.

The NFPA 1901 standard defines the minimum seat head height of 940 mm for suspension-style seats and 889 mm for non-suspension-style seats; both were measured with the seat height adjustment in its lowest position. These dimensions are measured from the seat H-Point (or Seating Reference Point) which is an imaginary position representing the human pelvis joint. This position is approximately 97.6 mm above the depressed seat cushion and 134.3 mm ahead of the seat back (SAE, 1995) or 75 mm up from the non-depressed seat cushion surface and 130 mm ahead of the seat back (NFPA, 2008) (Fig. 2a).

This study provided updated firefighter anthropometry data to verify the seat dimensions and seatbelt lengths specified above. In addition, this study developed specifications for seat pan height (Fig. 2a), head support height (Fig. 2a), seat spacing at hip level (Fig. 2b), and knee clearance (seat fore-aft space) (Fig. 2c).

3. Methods

3.1. Critical anthropometric measurements associated with seat and seatbelt specifications

Fourteen dimensions relevant to the design of seats and seatbelts were measured in this study. The definitions of these dimensions are listed in Appendix A and the inferences of these dimensions are summarized in Table 1. Seven of the 14 measurements were collected while the participants were wearing their personal turnout gear, including personal selection of tools stored in their pockets, in an erect seated posture. The remaining seven measurements were collected when the participants were in fitted