Designation: F3031 – 17 (Reapproved 2022)

Standard Practice for Range of Motion Evaluation of First Responder's Protective Ensembles[1]

This standard is issued under the fixed designation F3031; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Protective ensembles such as firefighter turnout gear, HAZMAT suits, etc., may impose a negative ergonomic impact on the wearer. This impact may involve restriction of movement and overall discomfort to the wearer. The possible increased restrictions of mobility during the use of protective ensembles may result in injuries to the musculoskeletal system, decreased performance, and decreased comfort. It is up to the end user to decide the meaningfulness of the information provided with the use of this standard for the performance of his/her job. This ergonomic standard practice is to determine and report the range of motion (ROM) of the protective ensemble or base ensemble, or both, and has been designed to allow for comparisons of the ROM between ensembles of the same class (firefighter turnout gear) and from different classes (firefighter ensemble versus HAZMAT suit).

1. Scope

1.1 This practice specifies the test equipment and procedures for assessing ROM on subjects wearing a protective clothing ensemble.

1.2 This practice covers the ergonomic measurements of range of motion and subjective perceptions.

1.3 To increase safety during testing, this practice requires the use of human participants who meet specific health and physical fitness requirements.

1.4 This practice does not attempt to determine other clothing characteristics, such as thermal insulation and evaporative resistance of the protective clothing ensemble. Test Methods F1291 and F2370 can be used for these measurements.

1.5 The values stated in this standard shall be SI units.

1.6 It is the responsibility of the test laboratory to obtain the necessary and appropriate approval(s) required by their institution for conducting tests using human participants.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F1291 Test Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin

F1494 Terminology Relating to Protective Clothing

F2370 Test Method for Measuring the Evaporative Resistance of Clothing Using a Sweating Manikin

2.2 *BSI Standards:*[3]

BS EN 469 Protective Clothing for Firefighters – Performance Requirements for Protective Clothing for Firefighting

BS 8469 Personal Protective Equipment for Firefighters – Assessment of Ergonomic Performance and Compatibility – Requirements and Test Methods

[1] This practice is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.60 on Human Factors.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from British Standards Institution (BSI), 389 Chiswick High Rd., London W4 4AL, U.K., http://www.bsigroup.com.

2.3 *ISO Standard:*[4]

ISO 10551 Ergonomics of the Thermal Environment – Assessment of the Influence of the Thermal Environment Using Subjective Judgement Scales

3. Terminology

3.1 *Definitions:*

3.1.1 Refer to Terminology F1494 for definitions of terms used in this practice.

3.1.2 *clothing ensemble, n*—for first responders, a protective ensemble.

4. Significance and Use

4.1 This practice can be used for the evaluation of the ROM of protective clothing ensembles worn under controlled conditions and can provide guidelines for the motion evaluation of PPE.

4.1.1 This practice utilizes a space large enough to allow users to move freely during the tasks and a chair and a stretcher to measure certain body joint mobility.

NOTE 1—Since required range of motion values will be related to the work task to be done while wearing the protective ensemble, the end user should decide meaningfulness of the information provided by this standard for the performance of their job.

4.2 This practice establishes general procedures for the evaluation based on the measurement of range of motion and subjective perceptions.

4.2.1 The data obtained can be used to evaluate the ROM of the test participant while wearing a protective clothing ensemble.

4.2.2 The data are also potentially useful in the research and development of advanced ensembles that are designed for optimal mobility and comfort or reduce strain on the wearer thereby reducing the potential injury associated with wearing the protective clothing ensemble.

4.2.3 The data are also potentially useful for first responder organizations to compare the ROM while wearing different ensembles.

4.2.4 This practice could also be used by consensus standards organizations in the development of ergonomic test criteria for protective ensembles.

4.3 Departures from the instructions in this practice have the potential to lead to significantly different test results. Technical knowledge concerning mobility of body joints, subjective evaluations, and testing practices is needed to evaluate which departures from the instructions given in this practice are significant. All departures must be reported with the results.

5. Apparatus

5.1 *Laboratory Space with Environmental Measures*—A room that is large enough to accommodate the tasks that the test participant will perform. Also, the room conditions shall be stable and recorded during testing. Use standard lab equipment to measure the ambient environmental conditions under which the testing occurs.

5.1.1 *Relative Humidity Measurement*—Use a humidity-sensing device and have an accuracy of ±5 % relative humidity and a repeatability of ±3 % to be acceptable (for example, wet bulb/dry bulb, dew point hygrometer).

5.1.2 *Air Temperature Sensors*—Use shielded air temperature sensors. The sensor shall have an overall accuracy of ±0.15 °C (for example, resistance temperature detectors (RTDs), thermocouple, sensor). The sensor shall have a time constant not exceeding 1 min.

5.2 *Measuring Mobility*—Standard instruments include a flexible tape measure, circumference tape, washable marker, and platform scale to perform anthropometric measurements. Use specific ergonomic assessment equipment during ergonomic assessments: large- and small-joint goniometer or electro-goniometer, flex tester sit-and-reach flexibility test box, and skinfold caliper.

5.3 *Measuring Subjective Perceptions*—Assess subjective perceptions, as it relates to ROM. Refer to ISO 10551 for the instructions on creating and using judgement scales.

5.4 *Participant Clothing Ensembles*—Choose and wear base ensemble clothing (of identical design and construction) that is appropriate for all of the different ensembles that are being evaluated. If the base ensemble is not specified, then a T-shirt, athletic shorts, socks, and underwear shall be used as the default base ensemble and shall be constructed of 100 % cotton where possible. Sock selection shall be based on the type of footwear used (for example, boot socks with boots). The participant must wear identical base ensemble clothing and shoes for all the tests for which they are involved, even if the test sessions occur on different days. The base ensemble worn must be recorded each session.

5.4.1 If intended to be reused or laundered, launder ensemble in accordance with the manufacturer's instructions. Set the number of laundering cycles to be consistent with the objectives of the testing.

5.4.2 *Athletic Shoes*—Wear athletic shoes with a soft rubber sole during testing, unless the protective ensemble includes footwear as part of the ensemble or if its instructions for use list a required type of footwear.

5.4.3 As needed between wear test sessions, protective clothing ensembles shall be cleaned in accordance with the manufacturer's instructions. The number of cleanings/launderings shall be recorded and reported.

6. Sampling, Participants, and Familiarization Period

6.1 *Sampling*—Test a minimum of eight different participants to evaluate the performance of each protective clothing ensemble.

6.2 *Test Participants*—Individuals who participate in this test shall do so strictly on a volunteer basis. Test laboratories shall adhere to all internal regulations regarding human testing and obtain the required human testing approval from their respective institutions. Participants shall be informed of all the details of this standard practice and the associated risks and benefits prior to providing their informed written consent. Complete anonymity and confidentiality shall be given to each participant.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

6.2.1 Select test participants either from a general population or a specific target population (for example, firefighters).

6.2.2 *Medical Evaluation*—If the respective institutional review committee's rules and regulations for ergonomic research require a medical evaluation or screening, have one completed for each test subject prior to the evaluation.

6.2.3 *Participant Gender*—Unless a specific target population is being evaluated, select participants of either gender.

6.2.4 *Participant Age and Stature*—Unless a specific target population is being evaluated, select adults between the ages of 18 and 55 years. If testing males, the body mass of the participants shall be between 65 and 100 kg (143 and 220 lb) and body height between 1.70 and 1.95 m (67 and 77 in.). If testing females, the body mass of the participants shall be between 50 and 90 kg (110 and 198 lb) and body height between 1.60 and 1.85 m (63 and 73 in.).

NOTE 2—Other heights and weights should be considered if a specific group of individuals is the main focus of the ergonomics evaluation.

6.2.5 *Ensemble Sizing*—Choose protective ensembles for each test subject based on sizing information provided by the garment manufacturer.

6.2.6 *Test Sessions*—Commit participants to multiple test sessions as needed depending on the number of ensembles to be evaluated.

6.3 *Familiarization Period*—Provide a test familiarization session prior to the actual testing for the purpose of introducing individuals to the test protocol and allowing them to become familiar with the protective clothing ensemble, the measurements being obtained, and the laboratory test area.

6.4 *Safety Provisions*—Authorize each test subject to terminate testing for any reason without penalty. There must be an established emergency response routine in the event of a significant adverse response to the test.

7. Procedure

7.1 *Environmental Test Conditions*—Standardize the environmental conditions provided below for all tests.

7.1.1 *Air Velocity*—Set air velocity at a level that is appropriate for the protective clothing ensembles being tested. If air velocity is not specified, choose an air velocity of no greater than 0.5 m/s as the default value.

7.1.2 *Relative Humidity*—Set relative humidity at a level that is appropriate for the protective clothing ensembles being tested. Relative humidity shall be controlled during testing within a range of ±5 %. If relative humidity is not specified, 50 % shall be used as the default value.

7.1.3 *Air Temperature*—Set air temperature at a level that is appropriate for the protective clothing ensembles being tested. Air temperature shall be controlled during testing within a range of ±1 °C. If air temperature is not specified, 21 °C shall be used as the default value.

7.2 *Ergonomic Measurements*—Base the evaluation of the protective ensemble on range of motion and ratings of comfort as it relates to ROM.

7.2.1 *Range of Motion (ROM)*—Assess the impact on the wearers of the protective ensemble by measuring the range of motion of most of the body joints.

7.2.1.1 *Static ROM*—Assess ensemble impact by measuring the degrees of maximal displacement/flexibility of different body joints.

7.2.1.2 *Shoulder Flexion:*

Start Position: The subject is supine. The arm is at the side, with the palm facing medially.

End Position: Subject remains supine, dominant humerus has moved anteriorly and dominant shoulder is fully flexed (without shoulder elevation). See Appendix X1.

Goniometer Position: Place the goniometer axis at the center and at the lateral aspect of the humeral head. This is approximately 2.5 cm inferior to the lateral aspect of the acromion process. Place the stationary arm lateral to the subject's dominant side in the sagittal plane, running along the mid-axillarly line, and pointing toward the floor. Place the movable arm parallel to the humeral longitudinal axis, and pointing toward the lateral epicondyle of the humerus. The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.3 *Shoulder Abduction:*

Start Position: Subject is standing in anatomical position.

End Position: The dominant arm has moved laterally to full shoulder abduction without elevating the shoulder or flexing the elbow. See Appendix X1.

Goniometer Position: Place the goniometer axis at the midpoint of posterior aspect of the glenohumeral joint. This is approximately 1.3 cm inferiolateral to the coracoid process. Place the stationary arm parallel to the coronal plane, on the posterior aspect of the humerus (when in anatomical position) and pointing toward the floor. Place the movable arm parallel to the longitudinal axis of the humerus (throughout the motion). The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.4 *Cervical Rotation:*

Start Position: Subject is seated with the head and neck in anatomical position.

End Position: The subject's neck is rotated to the limit of motion in both directions. See Appendix X1.

Goniometer Position: Place one goniometer strap around the chin and over the top of the head. Place the dial at the center of the top of the head. The assessed value shall be the total degrees of movement from the starting to the ending position, recording both directions.

7.2.1.5 *Cervical Flexion and Extension:*

Start Position: Subject is seated with the head and neck in anatomical position.

End Position: Subject's neck is flexed or extended to the limit of motion. See Appendix X1.

Goniometer Position: Place one goniometer strap around the head at the mid-forehead level and the dial on the lateral aspect of the head. The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.6 *Trunk Flexion – Lumbar Spine:*

Start Position: Subject standing in anatomical position (feet shoulder width apart).

End Position: The trunk is flexed (forward bend) to the limit of motion. See Appendix X1.

Goniometer Position: Place one goniometer strap around the trunk at a level 10 cm (4 in.) above the S2 spinous process. Place the dial on the lateral aspect of the trunk. The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.7 *Trunk Extension – Lumbar Spine:*

Start Position: Subject is standing, feet shoulder width apart with hands placed on the iliac crests. See Appendix X1.

End Position: Subject is standing with the trunk to the limit of motion.

Goniometer Position: Place one goniometer strap around the trunk at a level 10 cm (4 in.) above the S2 spinous process. Place the dial on the lateral aspect of the trunk. The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.8 *Trunk-Lateral Flexion:*

Start Position: Subject standing, feet shoulder width apart.

End Position: Subject in lateral trunk flexion to the limit of motion. See Appendix X1.

Goniometer Position: Place one goniometer strap around the trunk at a level 10 cm (4 in.) above the S2 spinous process. Place the dial on the anterior aspect on the trunk. The assessed value shall be the total degrees of movement from the starting to the ending position.

7.2.1.9 *Sit and Reach:*

Start Position: Seated on the floor with shoes removed, feet flat against the sit-and-reach box, and legs straight (not hyperextended).

End Position: Subject seated with interlocked hands, reaching forward, and has pushed the measuring apparatus forward as far as possible without straining, trunk rotation, or repetitive forward movement. See Appendix X1. The assessed value is that revealed by the measuring apparatus of the sit-and-reach box.

7.2.1.10 *Stand and Reach*—A tape measure shall be attached to the wall (adjacent to that which the subject is standing against) at shoulder height and parallel to the ground. The "0" mark will be positioned at the tip of the third finger in Position A.

Start Position: Subject standing with feet shoulder width apart and dorsal surface of the body in contact with a wall (in a corner with the dominant side of the body against the adjacent wall). Subject's arms shall be at the side with palms facing inward.

Position A: Dominant arm is raised to shoulder height with palm facing down.

End Position: Subject reaching forward as far as possible, without waist rotation. (Trunk flexion is allowed.) See Appendix X1. Using the tip of the third finger as the point of reference, the measurement recorded is the distance, using the tape measure, that the subject moves from Position A to Position B.

7.2.1.11 *Overhead Reach:*

Start Position: Subject is standing with feet shoulder width apart and dorsal surface of the body in contact with a wall. Subject's arms shall be at the side with palms facing inward.

End Position: Subject reaching arms as high as possible, directly above the head, and with palms facing inward. Arms are straight, but not hyperextended and shoulders are not elevated; movement shall be explained by the technician and practiced by the subject to avoid shoulder elevation. See Appendix X1. The measurement recorded is from the ground to the tip of the third finger.

7.2.2 *Subjective Perceptions*—Subjective assessment shall be performed by rating several aspects of the test, such as mobility, interaction between the different parts of the ensemble, or fit. This assessment shall be conducted prior to (after donning the protective clothing ensemble and moving around for about 2 min) and after the full ROM assessment.

7.2.2.1 *Ergonomics*—Give the subjective perception scale to participant, who shall give a number that best describes his/her perception of overall wearing mobility, upper body mobility, lower body mobility, and arm/shoulder mobility.

7.2.2.2 *Other Questions Included in the Ergonomics Assessment*—Give the subjective perception scale to the participant, who shall give a number that best describes his/her perception of (*1*) stability (or security, or both) of ensemble components, fastenings, and adjustments, and (*2*) interaction (or operation ease, or both) of specific parts (name which ones) of the ensemble, its components with the ensemble, or combinations thereof.

7.2.2.3 Ask the subject to identify factors of the ensemble that alter mobility, fit, or comfort (for example, weight or balance).

7.3 *Test Procedures:*

7.3.1 Upon arriving at the test laboratory, the participant shall be required to change into the appropriate base ensemble. Make anthropometrical measurements of age in years, mass to the nearest 0.01 kg (first nude, then with the base ensemble), and height to the nearest centimeter. Obtain the mass of the base ensemble and protective ensemble to the nearest 0.01 kg, prior to wearing by participant.

7.3.2 Each of the ergonomic measurements described in 7.2 shall be completed by the participant. Conduct a minimum of three repetitions for each measurement. To standardize each measurement, take three values on the side of the body coinciding with the subject's dominant hand.

7.3.3 The base ensemble or protective ensemble worn over the base ensemble shall be donned/doffed by the participant.

7.3.3.1 The protective ensembles shall be tested with each participant evaluated with all ROM assessments. Multiple ensembles may be compared or an ensemble may be compared to a base ensemble (5.4).

7.3.4 At no time shall the participant be left unattended during the test.

7.3.5 Fluid consumption (water) shall be allowed during the testing.

7.3.6 End the testing of any participant before the planned test battery is completed if that participant withdraws voluntarily, or if the participant shows adverse medical signs and symptoms, such as signs of impending heat illness (for example, disorientation, chills, or nausea).

8. Calculation or Interpretation of Results

8.1 Calculate the average of all measurements in millimeters (or angular degrees) for ROM. Use these average values to perform appropriate statistical analysis of the data (that is, range of motion).

8.2 Perform a statistical analysis on the different protective clothing ensembles using the variables measured.

8.3 Use a repeated measure ANOVA for comparing ROM and comfort or ergonomics measurements in each of the different protective clothing ensembles.

NOTE 3—It is recommended that a repeated measure analysis of variance (ANOVA) (multiple ensembles comparison) or t-test (two ensembles) be used with an appropriate post-hoc test when suitable.

8.4 Calculate the percentages of ROM change between ensembles.

9. Report

9.1 State that the specimens were tested as directed in this practice.

9.2 Report the test location, the institution, and the date(s) of testing.

9.3 Indicate that all participants used in this test were selected as directed in the standard, and that all individuals met the medical evaluation required by the institution conducting the test and signed an informed consent form as appropriate.

9.4 Report the average and median age, mass, and height of the participants by participant gender and overall.

9.5 Report the room environmental conditions of temperature, relative humidity, and wind speed for each test session and participant.

9.6 Describe the base ensemble used.

9.7 Describe the protective ensembles used, including boots, gloves, helmets, respiratory protection, or other equipment worn if applicable. Include the manufacturer's model and part number as well as a general description of each ensemble component used. Additionally, report the mass of each protective ensemble.

9.8 Report whether the ensemble has been laundered and the procedures used for its laundering.

9.9 Report the average range of motion and subjective ratings for all ensembles tested.

9.10 Report the results of the statistical analysis comparing the ensembles tested.

9.11 Report a summary of results with data from all the measurements, including the total number of test subjects used and the total number of replicates per subject.

9.12 Record the reason for any test termination.

9.13 Report and explain any modifications or departures from the specified practice.

10. Keywords

10.1 ergonomic performance; goniometry; protective ensembles; range of motion; subjective perceptions

APPENDIX

(Nonmandatory Information)

X1. PHOTOGRAPHS OF THE ERGONOMIC MEASUREMENTS

X1.1 See Figs. X1.1-X1.10.

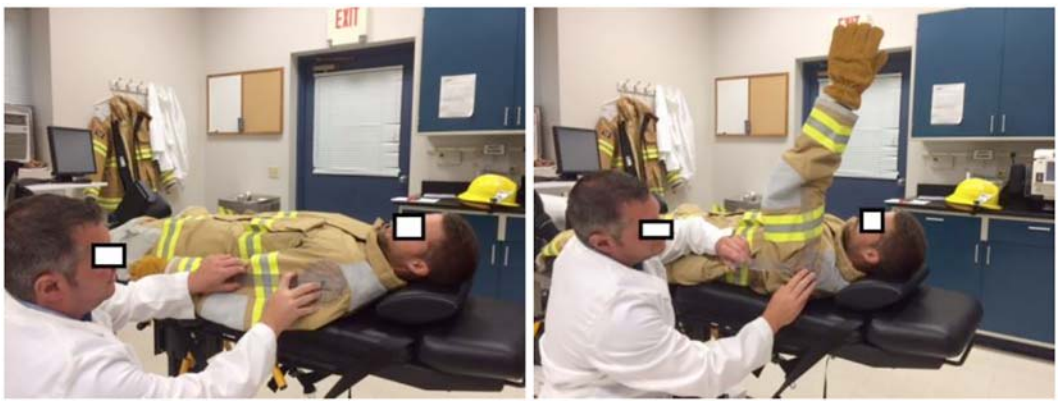

FIG. X1.1 Shoulder Flexion