Designation: F3517 – 21

Standard Practice for Movement Tests When Using an Exoskeleton[1]

This standard is issued under the fixed designation F3517; 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.

1. Scope

1.1 This practice provides a structure for documenting test methods used to evaluate exoskeleton success criteria during a requested movement task and to ensure the movements can be completed to the criteria specified by the test requestor. The practice describes movement tasks, such as walking, running, transitioning, crawling, climbing, jumping, and combinations thereof, while not wearing and wearing an exoskeleton and while not handling or handling loads. The practice does not describe all movement tasks, types, or methods. Instead, this standard provides exoskeleton manufacturers and users with example movement test procedures for common movement tasks and a method to record movement and test parameters so that movement tasks can be replicated. The practice includes designs for a movement apparatus, and the appendix provides design details.

1.2 The test requestor shall provide input to the evaluation and provide the evaluation method, which may come from another standard, and should include, for example: precision, statistical validity, population selection criteria, and environmental conditions.

1.3 Output of the evaluation, that is, success criteria, are provided by the requestor. Movement tests may include success criteria for the user, such as: move to a goal, continuously move, or combinations thereof.

1.4 User movements may contain single or multiple joints.

1.5 Movements may include the user being within or outside of the exoskeleton during the test and may include the exoskeleton moving the user, or the user moving the exoskeleton, or combinations thereof.

1.6 If possible, tests using real or artifact test spaces and loads should be replicable and performed under environmental conditions representative of a real-world movement implementation.

1.7 The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to imperial units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only and are not considered standard.

1.8 *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.*

1.9 *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]

F3323 Terminology for Exoskeletons and Exosuits

F3427 Practice for Documenting Environmental Conditions for Utilization with Exoskeleton Test Methods

F3443 Practice for Load Handling When Using an Exoskeleton

F3474 Practice for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics

2.2 *Other Standards:*

ISO 13482:2014 Robots and robotic devices -- Safety requirements for personal care robots[3]

3. Terminology

3.1 General terminology for ASTM Committee F48 standards are listed in Terminology F3323. Terminology specific to this standard are shown in this section.

[1] This practice is under the jurisdiction of ASTM Committee F48 on Exoskeletons and Exosuits and is the direct responsibility of Subcommittee F48.03 on Task Performance and Environmental Considerations.

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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 International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, https://www.iso.org.

3.2 *Definitions:*

3.2.1 *apparatus, n*—a structure, object, test component, or artifact thereof, found or placed in an environment and used for a test.

3.2.2 *artifact, n*—a representative of real structure(s), object(s), or test component(s) and used for a test.

3.2.3 *movement*—a particular instance or manner of displacement in space.

4. Summary of Practice

4.1 This practice is outlined as follows:

4.1.1 The significance and use section (Section 5) explains the relevance and meaning of the practice beginning with a figure showing a flow chart for performing exoskeleton-user movement tests.

4.1.2 The movements section (Section 6) describes typical user (Terminology F3323 defines 'user' as a person or animal who wears an exoskeleton) movements and their descriptions, including: fundamental movement patterns, foundational patterns, and isolated active joint motions. The section also briefly describes movement measurement where measurement data evaluation occurs beyond this practice.

4.1.3 The implementations, apparatus, and artifacts section (Section 7) describes typical sector implementations and associated apparatus(es) used in movement tests. It also describes reconfigurable artifacts that generically simulate real-world implementations and apparatuses for use in movement tests.

4.1.4 A test method then begins with a scope section (Section 8) describing example movement tests and procedures for test documentation guidance so that test replication can occur. The examples can be used directly or for guidance to apply to unique movement tests as requested.

4.1.5 The test method significance and use section (Section 9) describes the meaning and suitability of the movement test for exoskeleton evaluation and assumptions that may affect the results.

4.1.6 Safety hazards (Section 10) and warnings are described.

4.1.7 The guidance on statistical significance section (Section 11) describes the reliability of results based on probability of success for a specified number of test repetitions.

4.1.8 The procedure section (Section 12) describes the example test method steps to be performed and the information to be recorded for each repetition of the test so that test replication may occur.

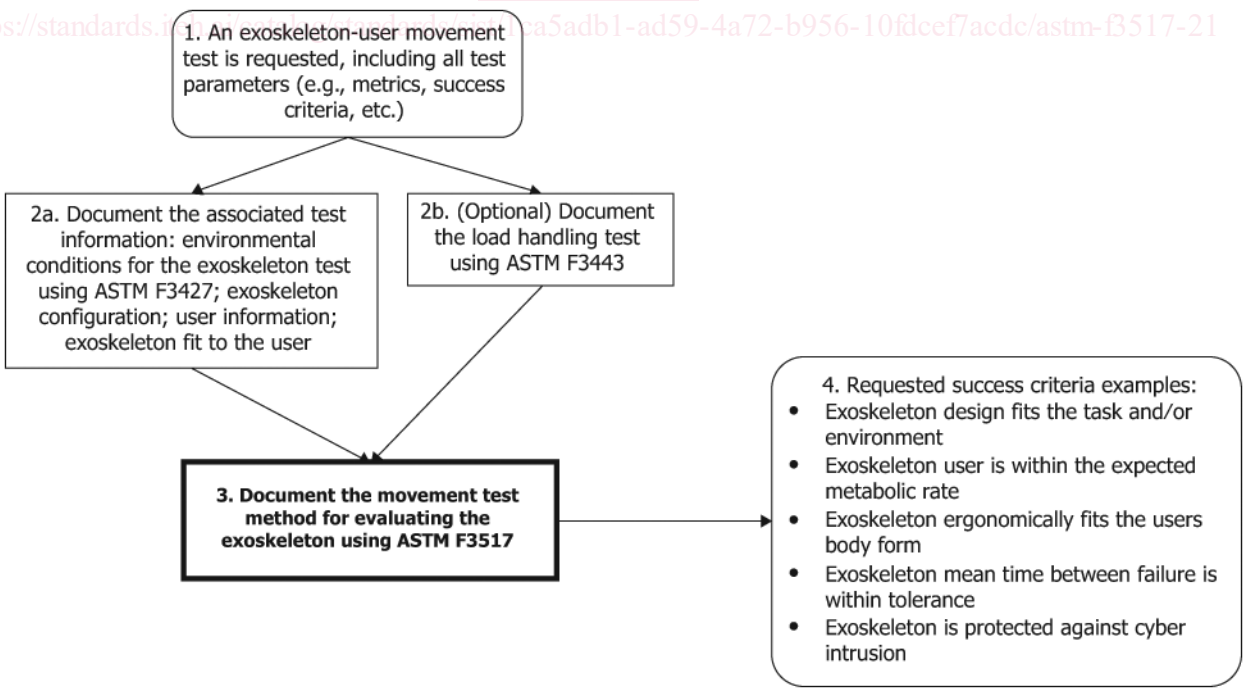
4.1.9 The precision and bias section (Section 13) provides an explanation of closeness of agreement between test results obtained and systematic errors that may occur in test results.

4.1.10 An example test report (Section 14) is provided and this section describes the report parameters to be documented.

4.2 An appendix of non-mandatory information to aid understanding and utilization of the standard includes: example movement test artifact designs and example movement test reports.

5. Significance and Use

5.1 This practice guides the user through selection and documentation of movement tests and procedures for use in evaluating exoskeletons while worn by the user. The practice is designed to allow replication of movements and tests. Fig. 1 shows a flow chart for performing movement test methods. Initially, the movement test is requested by a manufacturer, user/potential user, etc. as in box 1. The environment in which the test is to be performed is documented using Practice F3427



NOTE 1—This practice is shown in the bold outlined box #3.

FIG. 1 Flow Chart for Performing Exoskeleton-User Movement Test Methods

as in box 2a. If the movement test will also include an optional load handling test (for example, walking while carrying a load), the load handling portion of the test is documented using Practice F3443 as in box 2b. This practice is shown in box 3 where documentation of the movement and test results occurs. Evaluation of results occurs after the test has been completed as in box 4.

5.2 It is expected that this practice provides test guidance for many, although not all, movement activities using exoskeletons that may occur. However, the test method (see Section 8) provides examples to be used directly or as guidance for developing additional movement artifacts and movement tests.

6. Movements

6.1 The following subsections include typical movements and the applicable movement portions of the body that can occur when not wearing or wearing an exoskeleton. At any stage of its development, an exoskeleton can be tested using the generic movements described. The movements provide a generic list where, in many cases, combinations of movements can occur.

6.2 *Fundamental Movement Patterns:*

6.2.1 *Push*—Any pressing movement that involves displacing something away from the body (includes reaching for objects which involves pushing the hand toward the object).

6.2.2 *Pull*—Moving something toward the body.

6.2.3 *Hinge*—Rotating the hip joint to perform movements such as deadlifts, swings, and certain chopping and hammering movements with little or no knee flexion.

6.2.4 *Squat*—A movement involving a standing person lowering to a position in which the torso is erect and the knees are deeply bent and then rising to an upright position (**1**).[4]

6.2.5 *Lunge*—A movement involving a standing person stepping forward into a position in which the front knee is deeply bent while keeping the torso erect and then returning to the starting position.

6.2.6 *Twist*—Rotating the body (includes resisting rotation, also known as anti-rotation).

6.2.7 *Gait*—Patterns involving stepping, walking, or running.

6.3 *Foundational Patterns*—The fundamental movement patterns in 6.2 can be broken down further into the following foundational patterns required to perform each:

6.3.1 *Breathing*—Inhaling and exhaling;

6.3.2 *Head Movement*—Controlling and moving the head in response to environmental stimuli in any posture;

6.3.3 *Pushing Down*—Utilizing ground reactions forces from any posture by pushing down into the ground/implement/artifact;

6.3.4 *Weight Shifting*—Transferring weight between any point of contact with a supporting structure in any plane (sagittal, coronal, transverse, or some combination of these);

6.3.5 *Perturbations*—Moving the extremities one at a time or in some combination to reach for something or exaggerate a weight shift, such as moving a hand or foot away from the body; and

6.3.6 *Dissociation*—Moving the shoulders separately from the hips, or postures where the shoulders are not stacked directly above the hips.

6.4 *Isolated Active Joint Motions*—The fundamental and foundational movement patterns in 6.2 and 6.3 can also be broken down into isolated active joint motions which are well documented in anatomy and physiology texts, for example Reference (**2**). Examples of isolated active joint movements include, but are not limited to, the following:

6.4.1 *Flexion and Extension*—Decreasing (flexion) and increasing (extension) the angle between two body parts as viewed in the sagittal plane;

6.4.2 *Lateral Flexion (also known as side-bending)*—Active or passive bending movement of a body part in the coronal plane;

6.4.3 *Abduction and Adduction*—Motions of the limbs, hand, fingers, or toes in the coronal (medial-lateral) plane away from the body (abduction) or towards or across the midline of the body, or brings the fingers or toes together (adduction) (**3**);

6.4.4 *Circumduction*—Movement of the limb, hand, or fingers in a circular pattern, using the sequential combination of flexion, adduction, extension, and abduction motions (**3**);

6.4.5 *Rotation*—Rotation of the head/torso on the longitudinal axis of the spine (**4**);

6.4.6 *Internal and External Rotation*—Movement of a joint, around its long axis, towards (internal) or away (external) from the midline of the body (**5**);

6.4.7 *Supination and Pronation*—Act of turning the body to a supine position or of turning the horizontal forearm so that the palm of the hand faces upward (supination); the act of assuming the prone position, or the state of being prone (pronation) (**5**);

6.4.8 *Dorsiflexion and Plantarflexion*—Backward flexion or bending, as of the hand or foot (dorsiflexion); extension of the ankle, pointing of the foot and toes (plantarflexion) (**5**);

6.4.9 *Inversion and Eversion*—Turning inward, upside down, or in any direction contrary to the existing one (inversion); a turning inside out; a turning outward (eversion) (**5**);

6.4.10 *Protraction and Retraction*—Moving the shoulder blades (scapula) towards (protraction) or away from (retraction) the spine;

6.4.11 *Depression and Elevation*—Lowering (depression) or raising (elevation) of a body part above the horizontal midline;

6.4.12 *Medial and Lateral Excursion*—Movement towards the midline (medial excursion) and away from the midline (lateral excursion) (**4**);

6.4.13 *Superior and Inferior Rotation*—Rotation of the scapula during abduction: the glenoid cavity moves upward as the medial end of the scapular spine moves downward (superior rotation) and the glenoid cavity moves downward as the medial end of the scapular spine moves upward (inferior rotation) (**4**); and

[4] The boldface numbers in parentheses refer to a list of references at the end of this standard.

6.4.14 *Opposition and Reposition*—Movement and rotation of the thumb's tip towards (opposition) or away (reposition) from that of any other finger (**4**).

6.5 *Movement Measurement:*

6.5.1 Measurement of the effects of movement on the body can be found in Practice F3474, Section 4. These include two measurement areas:

6.5.1.1 Objective measures (for example, maximal oxygen uptake (VO2), blood pressure, blood-oxygen saturation, motion capture); and

6.5.1.2 Subjective measures (for example, rating of perceived exertion (RPE), rating of pain, soreness, discomfort, or comfort, or combinations thereof).

6.5.2 Physical body movement measurement devices can include sensors such as: optical tracking, inertial, camera, light detection and ranging (LIDAR), global positioning system (GPS), mechanical, and acoustic.

7. Implementations, Apparatus, and Artifacts

7.1 Exoskeleton implementations vary across sectors that apply exoskeletons for a variety of tasks. An exoskeleton implementation for one sector (for example, industrial/occupational material handling) may be quite different than in another sector (for example, military material handling), including different apparatuses, although may include the same exoskeleton used in different environments (see Practice F3427). A non-exhaustive list of sector implementations includes:

7.1.1 *Industrial/Occupational*—Warehouses, manufacturing plants, hospitals;

7.1.2 *Military*—Combat, logistics warehousing, maintenance;

7.1.3 *Response*—Rescue, firefighting, bomb disposal;

7.1.4 *Medical*—Rehabilitation, physical therapy, surgery; and

7.1.5 *Recreational/Entertainment*—Skiing, sport field/court setup/maintenance.

7.2 Examples of typical apparatuses that are in real-world exoskeleton implementations or used for testing exoskeletons in various sectors, or both, are shown in Table 1. The actual apparatus an exoskeleton user would interact with and the actual environment where someone would use an exoskeleton can be used for the movement test. For test replication, record exact details of the apparatus (for example, location, model number, dimensions, etc.). Alternatively, it may be more appropriate to test the exoskeleton with artifacts that simulate some or all of the apparatuses the exoskeleton user interacts with. See 7.3.

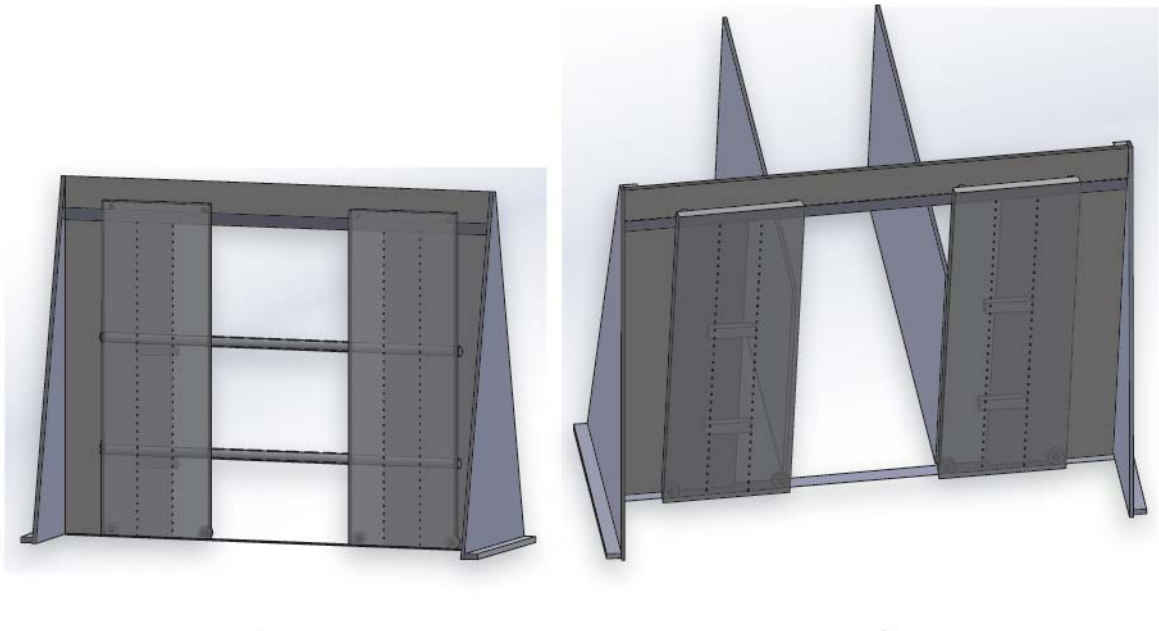
7.3 *Artifacts*—An artifact can be any object that reasonably simulates the loads, tools, or equipment with which an exoskeleton user would interact (for example, see Table 1). In general, the artifact should have the same size, mass, and mass distribution as the object it represents. In addition, the artifact should be reproducible so others can use it in testing. An artifact can also be something that closely simulates the environment where someone would use an exoskeleton. Aspects of the environment that can be simulated include things such as temperature and humidity, terrain, and the physical space. An environmental chamber is an example of an artifact to simulate aspects such as temperature and humidity. Artifacts can also be constructed to simulate terrains and aspects of the physical space where an exoskeleton will be used (for example, see Table 1). An example artifact is confined space that may not be readily available for exoskeleton manufacturers and users to perform repeatable and reconfigurable tests. Other useful artifacts may also be added to this standard in the future. Two standard confined-space artifacts are therefore provided here and labeled from the movement direction (that is, horizontal and vertical) of the exoskeleton-user. References for standard sized openings are provided in (**6-8**). Detailed designs to replicate the artifacts are provided in Appendix X1.

7.3.1 *Confined Pass-Through: Horizontal Movement:*

7.3.1.1 Fig. 2 shows a confined pass-through: horizontal movement artifact (a) as a wall and (b) as an aisle. The artifact

TABLE 1 Typical Movement Apparatuses for Each Sector that Exoskeleton Users may Encounter

Industrial/Occupational	Military	Response	Medical	Recreation/Entertainment
Carried loads, including:				
lumber, packages, parts for assembly, patient carriers, tires/wheels	ammunition, weapons, rucksack	jaws of life, stretcher	objects used in daily living, crutches, walker, cane	equipment bag
Gross Tools, including:				
drill, saw, screwdriver, wrench				skis and poles, golf clubs, bats
Precision Tools, including:				
jewelers screwdriver, small soldering iron			scalpel, dental drill	fishing lures and string
Wheeled, load carrying equipment, including:				
pallet jack, forklift, load cart, wheelchair, gurney	equipment cart, rough terrain container handler/ forklift	medical response cart, gurney	rolling walker	sporting equipment cart
Stairs, steps, railings Doorways, door knobs, aisles, hallways Indoor/outdoor obstacles and surfaces, including:				
walkway debris, furniture, equipment	curbs, walkway debris, undulating surfaces		walkway debris, furniture, equipment	sporting equipment
	manholes, floor access panels, windows, ship hatches, vehicle doors		car doors	
carpet, concrete, asphalt	sand, gravel, rubble, floor gaps		carpet, concrete, asphalt, treadmill	concrete/wood court, snow, dirt, sand



a b

FIG. 2 Confined Pass-Through: Horizontal Movement Artifact (a) Wall and (b) Aisle

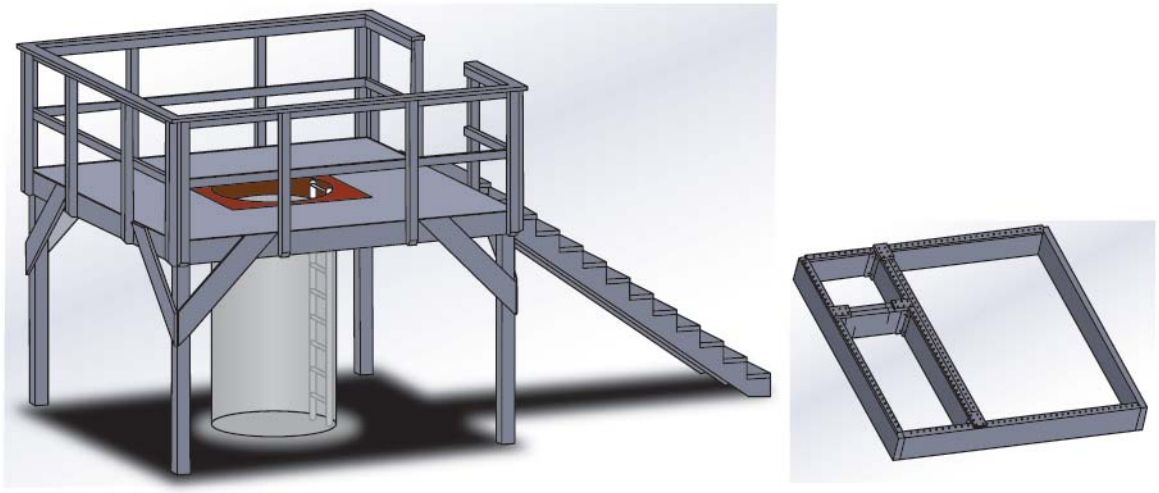
can simulate, for example, a ship door, an automobile door, or an aircraft fuselage aisle. The 3.7 m wide × 2.4 m high × 1.2 m deep artifact includes right and left sliding doors each measuring 2.3 m high × 0.8 m wide × 5 cm thick and supported by an upper metal rail and metal ground guide. The opening covered by the doors measures 2.1 m high × 1.8 m wide. Unless stated, the materials are intended to be off-the-shelf, cost-effective, common wood or plastic standard thicknesses. The doors define the opening width of the pass-through. As depicted in Fig. 2, plastic pipe height bars can be placed at various heights across the opening between the doors. The height bars are supported by metal angles attached to the doors with pins in the holes spaced vertically along the doors. A lower bar is used to pass under or over and an upper bar is used to pass under.

7.3.1.2 Vertical walls can optionally be added to the rear of the doors to create an aisle or hallway.

7.3.1.3 Movement of the height bars as the user passes through can be detected visually by the test technician or by electronic methods, for example, laser lines along the bars or tape switches attached to the bars and walls, or a combination thereof.

7.3.2 *Confined Pass-Through: Vertical Movement:*

7.3.2.1 Fig. 3 shows a confined pass-through: vertical



a b

FIG. 3 Confined Pass-Through: Vertical Movement Artifact
(a) Manhole (stair rails are removed for clarity, although are required for safety) and (b) Adjustable-size Rectangle Floor Access

movement artifact (a) manhole (stair rails are removed for clarity, although are required for safety) and (b) adjustable-size rectangle floor access insert. The artifact simulates, for example, manhole and floor access passages. Fig. 3(a) shows a red insert measuring 1.5 m square by 20 cm thick with a 1.2 m diameter opening simulating a manhole. The insert can be replaced with alternative access openings, for example with the adjustable-size rectangle floor access insert, with the same overall dimensions as the manhole insert, shown in Fig. 3(b). The platform measures 3.7 m square × 2.4 m high and uses standard decking materials and design (for example, outside deck rails, joist spacing, material thicknesses, railings, posts, stairs, etc.). For full vertical movement confinement, as with a manhole and transparently depicted in Fig. 3(a), a similar diameter tube to the insert opening can be added. Access to the tube from the ground level can also be added. A standard ladder is attached to the insert and the floor or the deck structure, providing vertical movement from deck to ground and vice versa.

7.3.2.2 User contact with insert surfaces as they pass through can be detected visually by the test technician or by electronic methods. Methods such as wet paint or chalk on the inside insert access area will leave marks on the user and exoskeleton (that is, similar to crash dummy testing of automobiles); tape switches on the insert provide electronic contact detection, or a combination thereof.

TEST METHOD

8. Scope

8.1 This test method, as part of this Practice F3517, describes the procedure outlined in Fig. 1, and other relevant information to perform movement tests as described in Section 6.

8.2 As there are an infinite number of movement tasks that can be performed in the real-world using exoskeletons, this test method provides a series of test method examples for guidance on developing, documenting, and performing repeatable movement tests by exoskeleton users and manufacturers across many sectors.

8.3 *Test Method Examples*—The following are examples that can be used as a guide for developing and implementing movement tests when using exoskeletons. The test requestor and test supervisor should describe in detail the test performed as provided in these examples.

8.3.1 In all tests, the environmental conditions shall be fully described using Practice F3427. See an example environmental conditions test report in X2.1. A future standard for exoskeleton user information is currently under development.

8.3.2 In all tests, the exoskeleton configuration being tested shall be identified, uniquely named (for example make, model, configuration), and reported, including all subsystems and components with their respective features and functionalities. See an example exoskeleton configuration table in X2.2. A future standard for exoskeleton configuration is currently under development. The exoskeleton configuration should be representative of a configuration that will be used in its intended application. The exoskeleton configuration shall remain the same for all relevant tests to enable direct comparison of performance and to identify trade-offs between different configurations. If the configuration is changed during a test, it is considered a fault and the test is to be repeated. Documentation should include detailed photographs of the exoskeleton and apparatus.

8.3.3 In all tests, the same user shall be identified and named with user information reported that is associated with the exoskeleton and the test. See an example user information table in X2.3. A future standard for exoskeleton user information is currently under development.

8.3.4 In all tests, the fit of the exoskeleton to the user shall be reported. See an example user information table in X2.4. A future standard for exoskeleton fit to the user is currently under development.

8.3.5 In all tests, the exoskeleton-user movement test shall be reported. See Section 14 report and an example user information table in X2.4. A future standard for exoskeleton fit to the user is currently under development.

8.3.6 *Example 1 – Movement Through a Confined Space – Horizontal Movement (Industrial/Occupational, Military, Response):*

8.3.6.1 This test uses an actual car door opening measuring 48 in. wide × 48 in. high with the opening bottom being 40 cm above the floor (see Fig. 4(a)). The further confinement of a windshield angle is also noted and no seat confinement is added (that is, the seat is not installed during this phase of manufacturing). Alternatively, the confined pass-through – horizontal movement artifact shown in Fig. 2(a) is used for this test and is fixtured with the door opening matching the actual door opening of 91 cm wide × 122 cm high with the opening bottom being 40 cm above the floor. An angled bar matching the windshield angle is also added as shown in Fig. 4(b). Further confinement shall also be added to the artifact and noted if additional opening complexities exist. For example, curved areas or a raised floor as appropriate for the real application.

8.3.6.2 If curved confinements exist within the pass-through area, they are either (*1*) added to the confinement pass-through or (*2*) a limiting straight bar defining the chord between the two points at the most confined location is added to the apparatus. Note that (*2*) provides a slightly smaller confined pass-through.

8.3.6.3 Measurement of success or failure is by observation that confinement apparatus does not move or any part of the apparatus moves (for example, a height bar lifts). Alternatively, the confined pass-through opening can be lined with a tape switch for electronic contact detection of the apparatus by using a laser line emitter/detector sensor, optical tracking, cameras, or by other sensing means, any of which provide apparatus movement detection.

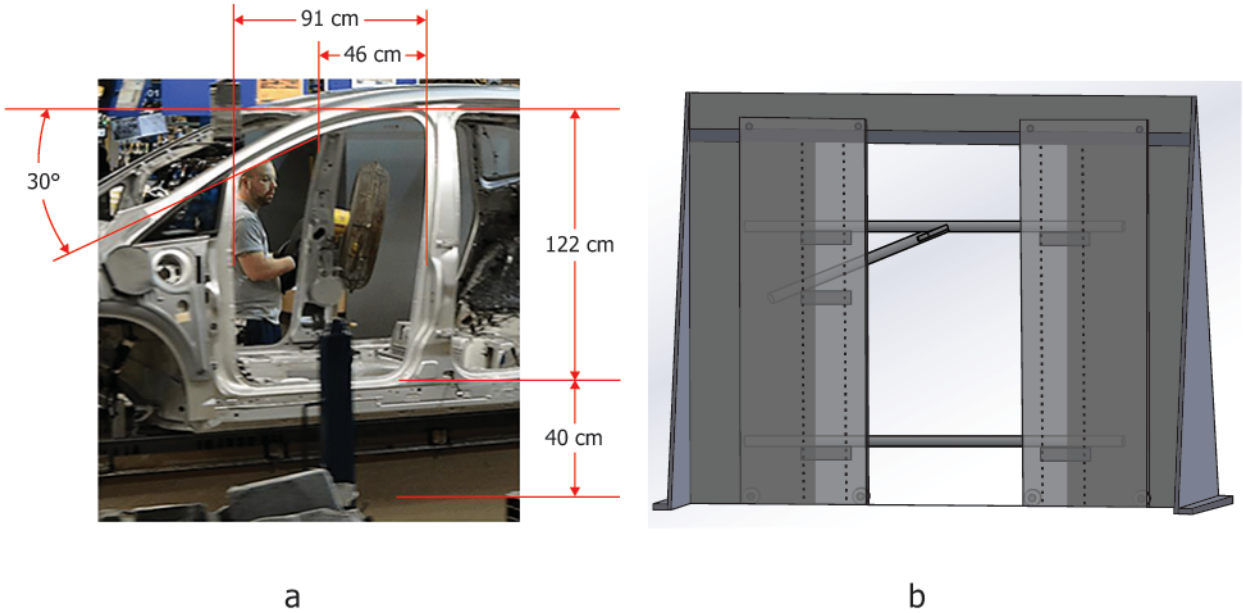


FIG. 4 Confined Space – Horizontal Movement Test Setup with:
(a) Real Car Door Opening and
(b) Confined Pass-Through – Horizontal Movement Artifact set up as a Car Door Opening

8.3.6.4 The user is instructed to don the exoskeleton and stand in front of the opening.

8.3.6.5 The user is instructed to carry any appropriate load (for example, tool) that will be used for the real-world application.

8.3.6.6 The user is instructed to pass through the opening while carrying the load. The test administrator monitors the confinement apparatus or artifact, while the user passes through the opening, using an agreed-upon measurement method as in 8.3.6.3. The test is successful if the user passes through the apparatus or artifact and any part of the apparatus or artifact moves less than the allowed amount as set by the test requestor. If the apparatus or artifact moves beyond the set amount, the test is failed.

8.3.6.7 The user is then instructed to pass back through the opening following the same guidelines as in 8.3.6.6.

8.3.6.8 The test supervisor notes all pertinent information to the test on the test report. Relevant photos of the environment, task, and load shall be attached.

8.3.6.9 Metrics are documented for the repetition.

8.3.6.10 The test is repeated 29 times (or as instructed by the test requestor).

8.3.7 *Example 2(a) – Static Shooting (Military, Response):*

8.3.7.1 This test uses a dummy weapon (rifle or pistol) (see Fig. 5) in an open space. A paper target could be placed at 50 m from the user if desired. The height of the target top should be placed at 6 ft.

8.3.7.2 Measurement of success or failure is by observation that the weapon can be readily moved from low ready to shouldered (or presented for pistol) and the user can acquire a target. Additionally, a laser sight can be placed on the weapon and used to measure weapon aim trace for a designated period of time such as 10 s or 15 s. The maximal horizontal and vertical distance would be calculated for each trial (Fig. 6).

8.3.7.3 The user is instructed to don the exoskeleton and stand with a weapon in both hands at the low ready position (Fig. 7).

8.3.7.4 The user is instructed to carry any appropriate load (for example, kit which could include body armor, extra magazines, or other supplies carried on the body) that will be used for the real-world application. If the exoskeleton is not compatible with these loads, this should be noted and the test continues without the loads.

8.3.7.5 The user is instructed to move the weapon from low ready, shoulder the rifle, or present the pistol to acquire the target on the test supervisor's verbal or mechanical cue. Once the target is acquired by the user, the user will announce 'sighted'. If using a laser aim trace, the user will continue to acquire the target while aim data are collected for the specific period of time (for example, 10 s or 15 s). After the specified time has passed, the test supervisor will announce 'done' at which time the user can return the weapon to low ready.

8.3.7.6 The test supervisor notes all pertinent information to the test on the test report. Relevant photos of the environment, task, and load shall be attached.

8.3.7.7 Metrics are documented for the repetition.

8.3.7.8 The test is repeated ten times (or as instructed by the test requestor).

8.3.8 *Example 2(b) – Shooting on the Move (Military, Response):*

8.3.8.1 This test uses a dummy weapon (rifle or pistol) in an open space. A paper target (see Fig. 5) is placed at a distance from the user that would allow the user to take at least six steps toward the target (see Fig. 8). The height of the target should be placed at 6 ft from the ground.

8.3.8.2 Measurement of success or failure is by observation that the weapon can be readily moved from low ready to shouldered (or presented for pistol), and the user can take at

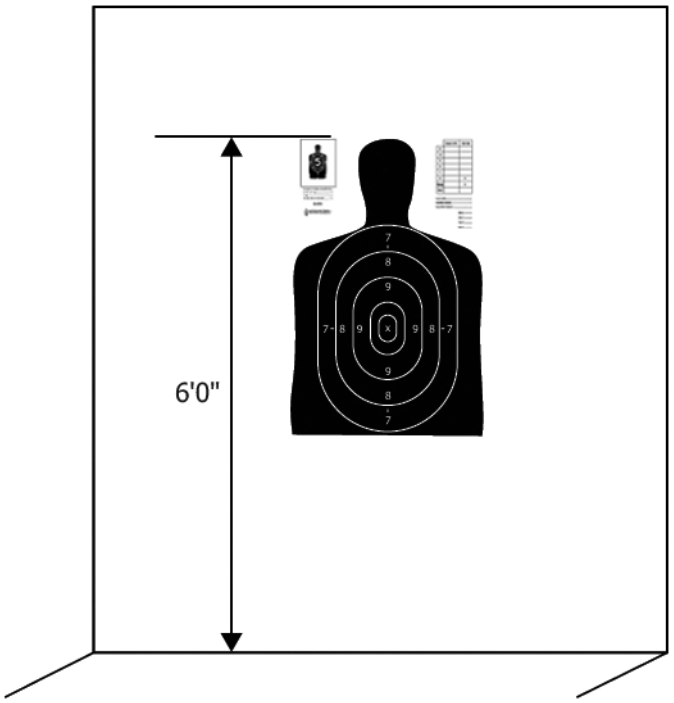


FIG. 5 Silhouette Target placed on a Wall at 50 m from the Exoskeleton User

least six steps toward the target while continuing to acquire a target. Additionally, a laser sight can be placed on the weapon and used to measure weapon aim trace while moving towards the target. The maximal horizontal and vertical distance would be calculated for each trial (see Fig. 6).

8.3.8.3 The user is instructed to don the exoskeleton and stand with a weapon in both hands at the low ready position (Fig. 7).

8.3.8.4 The user is instructed to carry any appropriate load (for example, kit which could include body armor, extra magazines, or other supplies carried on the body) that will be used for the real-world application. If the exoskeleton is not compatible with these loads, this should be noted and the test continues without the loads.

8.3.8.5 On the test supervisor's verbal or mechanical cue, the user is instructed to move the weapon from low ready, shoulder the rifle or present the pistol, and start walking forward while acquiring the target. If using a laser aim trace, the user will continue to acquire the target while aim data are collected for the specific number of steps. Once the user has walked at least six steps (that is, one right foot step and one left foot step equal to two steps total) the user is instructed to stop walking, return the weapon to low ready, and turn around to walk back to the start line.

8.3.8.6 The test supervisor notes all pertinent information to the test on the test report. Relevant photos of the environment, task, and load shall be attached.

8.3.8.7 Metrics are documented for the repetition.

8.3.8.8 The test is repeated ten times (or as instructed by the test requestor). Note that shooting on the move should be performed at a methodical, deliberate walking pace, generally around 2.0 mph.

8.3.9 *Traversing Terrains – Varying Orientation Ramps (Industrial/Occupational, Military, Response, Recreational):*

8.3.9.1 The subject is requested to traverse a terrain apparatus made of varying orientation, 15° ramps, as shown in Fig. 9, in a "figure 8" pattern and around barriers placed along the apparatus center axis and spaced 2 m between each.

8.3.9.2 The ramp terrain is an array of individual ramps that form peaks and valleys. Each ramp is independent, measuring 61 cm square on the ground so it can be rotated in place to form more difficult terrains. The ramp surface can be made of oriented strand board (OSB), plywood, or similar material. The entire apparatus of 4 ramps wide × 12 ramps long measures 2.4 m wide × 7.3 m long when fully assembled.

8.3.9.3 Optionally, as in Fig. 9(a), a supporting structure can be fabricated from lumber posts and OSB panels to surround and contain the ramp apparatus.

8.3.9.4 Ensure that the apparatus is prepared as in Fig. 9(b) and the environmental conditions are recorded.

8.3.9.5 The user is instructed to don the exoskeleton and stand at the start/end line. The test administrator ensures the subject understands that repetitions are successfully completed when any part of the subject crosses the start/end, breaking the vertical plane, without a fault.

8.3.9.6 Ensure the subject understands what a fault or other repetition pause is.

8.3.9.7 Practice within the test apparatus prior to the test is allowable to allow subject familiarity with the test procedures prior to conducting the test.

8.3.9.8 The subject is instructed to start on one side of the lane at the designated start point, not touching the start/end centerline.

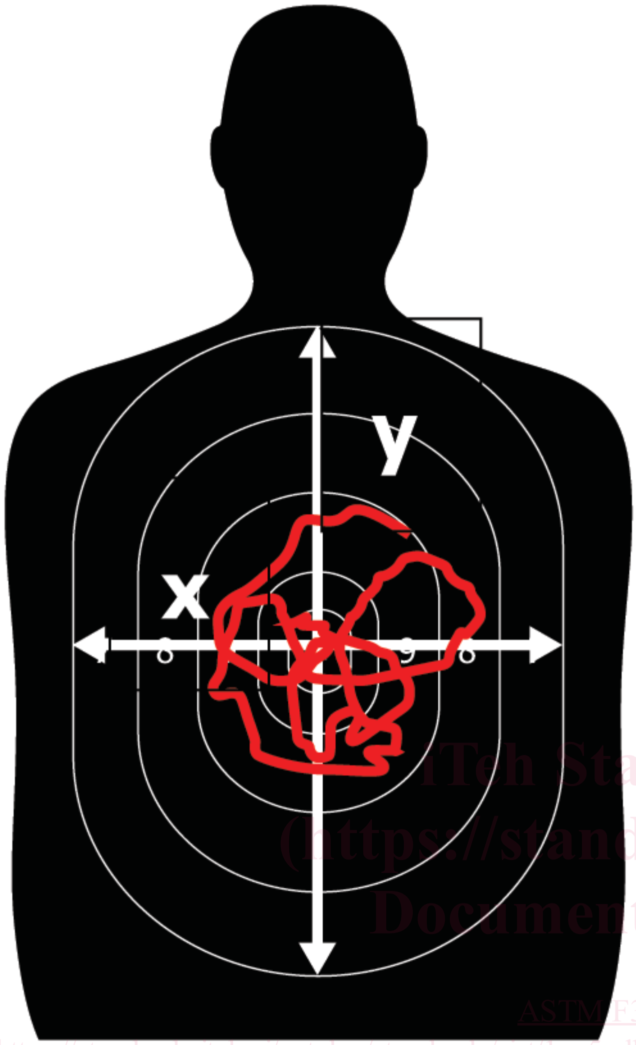


FIG. 6 Aim Trace (red) on Target to be Measured in the X and Y Directions

8.3.9.9 The timer is started when any part of the subject crosses the start/end centerline, breaking the vertical plane.

8.3.9.10 Record a successful repetition when any part of the subject crosses the start/end centerline of the lane without a fault.

8.3.9.11 Record a fault if any of the following occur during the test:

(1) If the subject damages the apparatus enough to need adjustment or repair, to return it to the initial condition for the next repetition;

(2) If the subject leaves the testing bay for any reason;

(3) If the subject loses balance and falls over; and

(4) If any part of the exoskeleton needs repair before completing the test.

8.3.9.12 Repeat repetitions using alternating ends of the lane until the test is complete or the timer expires.

8.3.9.13 Record the number of successful repetitions, faults, and elapsed time of the test.

FIG. 7 Low Ready Position for Rifle

8.3.9.14 Measurement of success is by successfully completing 30 repetitions without a fault or as directed by the test supervisor.

8.3.10 *Gait Training (Medical)*—Gait training for a patient with a gait disturbance due to a neurological deficit or disability (for example, spinal cord injury, traumatic brain injury, ankle brachial index, cerebrovascular accident, cerebral palsy, multiple sclerosis, amyotrophic lateral sclerosis, or Parkinson's disease) which requires use of an assistive device including an exoskeleton/exosuit.

8.3.10.1 This test is conducted on a flat, level, well-lit, indoor surface and uses an assistive device as appropriate to the current ability level that the patient needs to remain safe (parallel bars, walker, crutches, cane).

8.3.10.2 The walking course should be a predetermined, repeatable distance and an appropriate width to allow unrestricted gait within the space safely. For example, a lower level patient could use parallel bars (see Fig. 10) which have adjustable height and width to fit the needs of the patient. Safety measures should be taken to prevent falls.

8.3.10.3 Success or failure of the test is measured by the ability or inability to ambulate the predetermined distance without falls at a pre-established amount of assistance as stated in the goals for gait training (for example, stand by assist, contact guard, or minimum to maximum assist). Multiple aspects of gait training can be measured to provide metrics (for example, gait speed, symmetry, endurance, dual-task during gait, patient perceptions, and confidence).

8.3.10.4 The patient is instructed to don the exoskeleton (with or without assistance depending on the patient's level of function and capabilities) and stand at the marked start of the walking course with the prescribed assistive device.

8.3.10.5 The patient is instructed to complete the walking course adhering to the requested gait metrics (for example, for gait speed: "Complete the walking course at the established

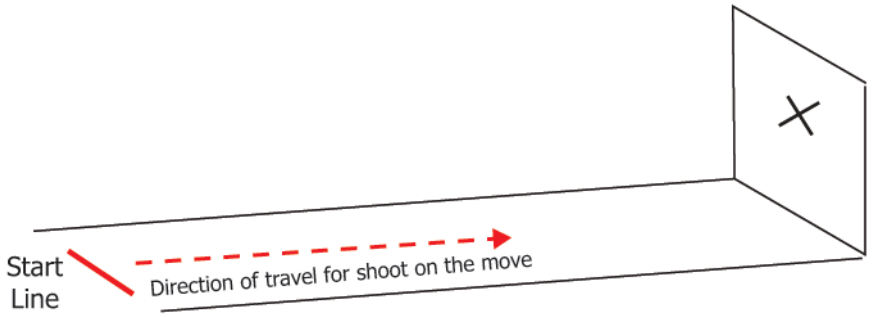


FIG. 8 Illustration of a Walkway with the Start Line (solid red line) and Direction of Travel (dashed red line) Toward the Target (black x) for Shooting on the Move

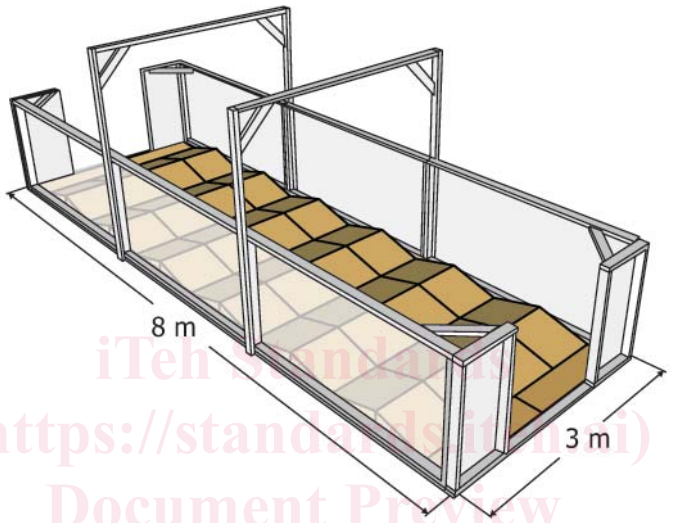
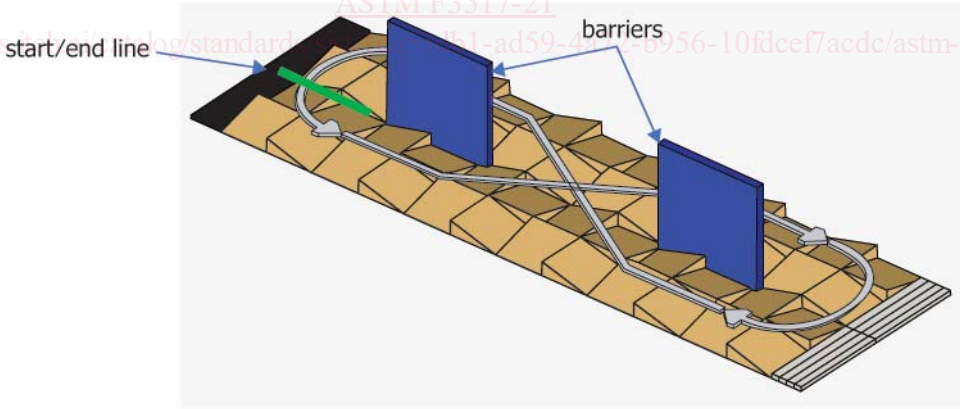


FIG. 9 Apparatus of Varying Orientation, 15° Ramps: (a) Aligned



b

FIG. 9 Apparatus of Varying Orientation, 15° Ramps: (b) Misaligned *(continued)*

speed while avoiding falls.") and to begin when the test supervisor states, "begin".

8.3.10.6 Data collection begins when the patient starts, and stops when the patient reaches the end of the walking course.

8.3.10.7 On successful completion of the gait repetition, objective and subjective metrics should be documented. Gait repetition can be video documented for reference of progression and study.

FIG. 10 Parallel Bars used for Gait Training

8.3.10.8 The user is allowed to rest between successive repetitions, if necessary, as set forth by the test requestor.

8.3.10.9 The requested gait repetition is repeated nine times.

8.3.11 *Moving a Victim in a Rescue Situation (Industrial/Occupational, Response, Military):*

8.3.11.1 This test uses a weighted mannequin or sandbags as artifacts to simulate the victim in a rescue situation. The weight of the simulated victim is specified by the test requestor. The weighted mannequin or sandbags should be lying on the floor or ground.

8.3.11.2 Two different techniques may be used to move the simulated victim. The first technique is the shoulder pull (Fig. 11). The second technique is the blanket pull (Fig. 12). This technique requires the use of a blanket, tarp, or similar item. The test requestor specifies one or both of the techniques for the test.

8.3.11.3 Measurement of success or failure is by observation that the user is able to move the simulated victim a distance specified by the test requestor. In addition, there can be requirements to move the simulated victim the specified distance in a time specified by the test requestor.

8.3.11.4 The user is instructed to don the exoskeleton and stand near the simulated victim's head.

8.3.11.5 The user is instructed to move the simulated victim by the technique specified. The test is successful if the user moves the simulated victim the specified distance (and if required, in the specified time). The test is a failure if the user is not able to move the simulated victim the specified distance (and if required, in the specified time).

8.3.11.6 The test supervisor notes all of the information pertinent to the test in the test report. Relevant photos of the test environment, test artifacts, and task shall be attached.

FIG. 11 Shoulder Pull

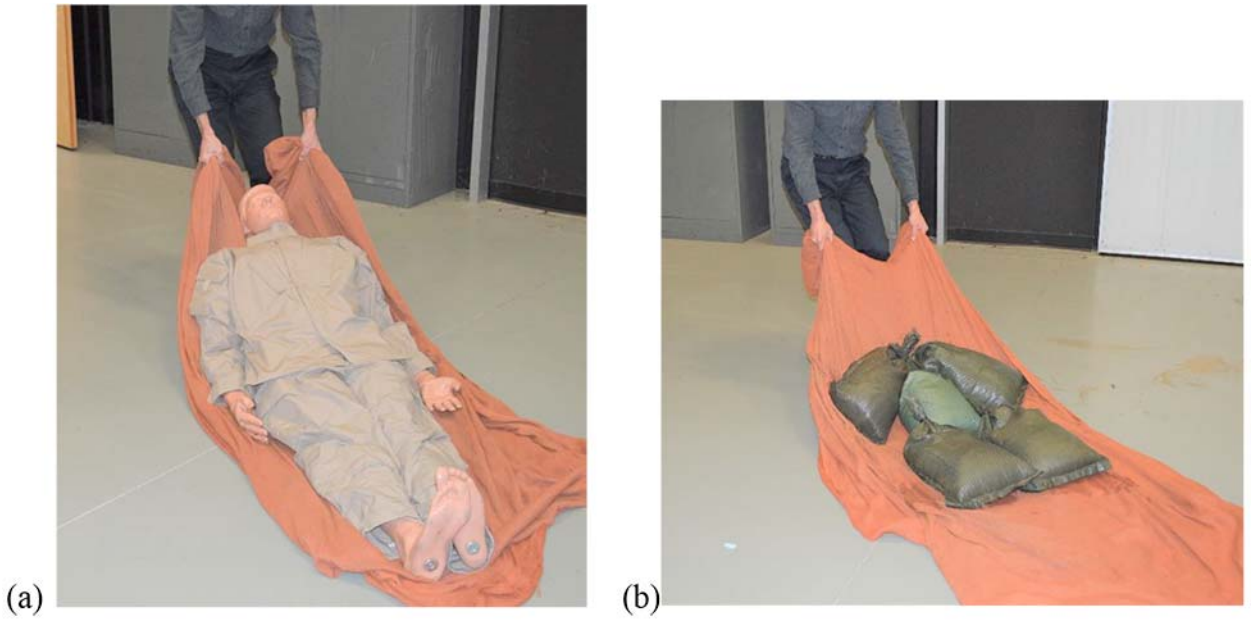


FIG. 12 Blanket Pull (a) Mannequin Artifact and (b) Sandbag Artifact

8.3.11.7 Metrics are documented for the repetition.

8.3.11.8 The test is repeated 29 times (for a total of 30 tests) or as specified by the test requestor.

8.3.12 *Downhill Skiing (Recreation, Response, Military):*

8.3.12.1 This test measures an exoskeleton user performing intermediate or higher capability downhill snow skiing at a location specified by the test requestor. Snow base, weather, and other environmental conditions are critical to this test as well as the test layout, and shall be documented in the Practice F3427 report with exact locations of trail characteristics (for example, straight, slalom flags, moguls/jumps, start and end lines) marked and measured for documentation.

8.3.12.2 The test participant, or exoskeleton user, shall be skilled in downhill snow skiing on blue square or higher difficulty trails. The test participant shall be tested on an open trail with no skiers within the participants' locale. The test participant shall initially perform a baseline set of no less than five tests to: (*1*) ski on and become comfortable with the test trail prior to performing the test using an exoskeleton and (*2*) provide the test supervisor a basis for how the participant skis for comparison to the test when using an exoskeleton. Familiarity with control of basic straight and side-to-side (slalom) skiing and turn or snowplow stopping shall be demonstrated by the participant. Optionally, if moguls, other ski jumps, or other changes to basic skiing are intended to be tested, familiarity with these options shall be demonstrated prior to testing.

8.3.12.3 Proper rest time and between test movement, for example, chairlift or other means for the participant to be moved from the bottom to the top of the trail, shall be provided to minimize the participant/user fatigue between baseline and exoskeleton tests.

8.3.12.4 The baseline set of tests shall be video recorded or other means of documenting the baseline set of tests, or both.

8.3.12.5 The user is instructed to don the exoskeleton and stand at a chosen start location at the top of the trail.

8.3.12.6 The user is instructed by the test supervisor to begin when ready. Recording of the test begins when the user begins skiing from the start location and continues throughout the entire trail until reaching the end line.

8.3.12.7 Success, as set by the test requestor prior to the test and deemed during the test by the test supervisor, is (*1*) if observation that the user is able to ski similar to or better than the participant performance during the baseline test set without fall or injury, and (*2*) performed within a set time by the test requestor prior to the test.

8.3.12.8 Failure, as set by the test requestor prior to the test and deemed during the test by the test supervisor, is (*1*) if the user is not able to ski similar to or skis worse than (for example, falls, becomes injured, slows, requires breaks) the participant performance during the baseline test set, (*2*) if the exoskeleton requires readjustment, reprogramming, or other change to the exoskeleton fit or configuration during the test, or (*3*) performed with more time as set by the test requestor prior to the test.

8.3.12.9 The test supervisor notes all the information pertinent to the test in the test report. Relevant photos and videos of the test environment, test artifacts (if any), and task shall be attached.

8.3.12.10 Metrics are documented for the repetitions.

8.3.12.11 The test is repeated 29 times (for a total of 30 tests) or as specified by the test requestor.

9. Test Method Significance and Use

9.1 Exoskeletons, dependent upon their design and implementation criteria, are intended to enable users to enhance movement tasks, such as walking, crawling, climbing, and load handling in real-world situations within industrial, medical, military, response, and entertainment/recreational applications. As movement tasks can infinitely vary, this test method allows manufacturers and users to fit exoskeleton-use to movement