Designation: F3581 – 22

Standard Test Method for Exoskeleton Use: Hurdles[1]

This standard is issued under the fixed designation F3581; 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 *Purpose:*

1.1.1 The purpose of this test method, as a part of a suite of exoskeleton use test methods, is to quantitatively evaluate an exoskeleton's (see Terminology F3323) safety (see 1.4) or performance, or both, for traversing hurdles.

1.1.2 Exoskeletons possess a certain set of allowable exoskeleton user movement capabilities, including user-motion adaptability, to suit operations such as: industrial/occupational, military, response, medical, or recreational. Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to traverse hurdles, as intended by the user or test requestor, while using an exoskeleton is essential for exoskeleton deployment for a variety of tasks (for example, traversing logs, objects). This test method specifies test setup, procedure, and recording to standardize this hurdles task for testing exoskeleton user movement.

1.1.3 Exoskeletons need to function as intended, regardless of types of tasks and terrain complexities (for example, carpet, metal, masonry, rock, wood). Required movement capabilities may include, for example: walking, running, crawling, climbing, traversing gaps, hurdles, stairs, slopes, various types of floor surfaces or terrains, or confined spaces, or any combination thereof. Standard test methods are required to evaluate whether or not exoskeletons meet these requirements.

1.1.4 ASTM Subcommittee F48.03 develops and maintains international standards for task performance and environmental considerations that include but are not limited to, standards for safety, quality, and efficiency. This subcommittee aims to develop standards for any exoskeleton application as exemplified as in 1.1.2. The F48.03 test suite consists of a set of test methods for evaluating exoskeleton capability requirements. This hurdles test method is a part of the test suite. The setup, procedure, and apparatuses associated with the test methods challenge specific exoskeleton capabilities in repeatable ways to facilitate comparison of different exoskeleton models or exoskeleton capabilities to tasks.

1.1.5 The test methods quantify elemental exoskeleton use capabilities necessary for sector applications listed in 1.1.2 and perhaps others. As such, users of this standard should use either the entire suite or a subset based on their particular requirements. Users are also allowed to weight particular test methods or particular metrics within a test method differently based on their specific requirements. The testing results should collectively represent an exoskeleton's overall safety or performance, or both, as required for the task. These performance data can be used: to guide procurement specifications, for acceptance testing, and for training to use exoskeletons intended for specified applications.

NOTE 1—Additional test methods within the suite are anticipated to be developed to address additional exoskeleton capability requirements, including newly identified requirements and even for new application domains.

1.2 *Exoskeleton*—The exoskeleton shall be used as intended by the manufacturer to perform the test described in this test method. If the exoskeleton is not designed for hurdles-use and the test requestor intends to use the exoskeleton to perform a hurdles test (for example, for research, development of hurdles-capable use by a manufacturer, hurdles training as in medical rehabilitation applications), appropriate manufacturer approvals should be sought prior to performing the test method.

1.3 *Performing Location*—This test method shall be performed in a testing laboratory or in the field where the specified apparatus and environmental conditions are implemented.

1.4 *Units*—The values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound 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.

1.5 *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] This test method 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.

Current edition approved Nov. 15, 2022. Published January 2023. DOI: 10.1520/F3581-22.

1.6 *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

F3444/F3444M Practice for Training Exoskeleton Users

F3474 Practice for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics

F3517 Practice for Movement Tests When Using an Exoskeleton

F3523 Test Method for Exoskeleton Use: Confined Space: Horizontal Movement

F3527 Guide for Assessing Risks Related to Implementation of Exoskeletons in Task-Specific Environments

F3528 Test Method for Exoskeleton Use: Gait

F3613 Practice for Recording the Exoskeleton Fit to the User

F3614 Practice for Recording the Exoskeleton User Information

2.2 *ISO Standards:*[3]

ISO 13482 Robots and robotic devices — Safety requirements for personal care robots

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

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 *hurdles, n*—one or more horizontal barriers or step platforms that a user is to traverse.

3.2.3 *test suite, n*—designed collection of test methods that are used, collectively, to evaluate an exoskeleton's safety and/or performance.

4. Summary of Test Method

4.1 The task for this test method, exoskeleton-user traversing hurdles, is defined as the exoskeleton-user performing a hurdles traversal test, including a number of repetitions as set by the test requestor. A test includes at least 5 repetitions to traverse one or more hurdles that have a change in height above ground height. See Fig. 1 for an illustration. Further, the test requestor can specify the statistical reliability and confidence levels of such a capability and, thus, dictate the number of successful task performance repetitions that are required.

4.2 The test includes two variations of hurdles: *(1)* barrier hurdle and *(2)* platform hurdle, briefly described as:

4.2.1 *Barrier Hurdle*—A short, relatively thin wall of which the user steps over.

4.2.2 *Platform Hurdle*—A raised level surface on which the user steps onto or from which the user steps down.

4.3 The test is described as follows:

4.3.1 This test can be used to assess aerobic function, endurance, hurdle traversal speed, or balance, or any combination thereof.

4.3.2 The test metrics can include, for example, the following:

4.3.2.1 Number of hurdles traversed,

4.3.2.2 Height of hurdles traversed,

4.3.2.3 Change(s) in user (for example, heart rate, fatigue, stability, balance, toe drag, stumbles, near falls/falls) by a specified amount,

4.3.2.4 Upon traversing the hurdle set, the ability to turn around on the floor or hurdle step and traverse the hurdle in the opposite direction or to descend the hurdle step.

4.4 For all tests, the specified START point to the END point, TURN point shall be defined by the test requestor prior to the test. This test method can be combined with other test methods, for example, Test Method F3528. The required apparatuses are described in Section 5.

4.5 For any hurdles test, return from the end marker past the start marker may commence as part of the test, or the user may begin each repetition from the start-to-end markers as set by the test requestor.

4.6 The hurdles test can include either or both of the barrier hurdle or platform hurdle tests as requested by the test requestor.

4.7 *Barrier Hurdle Test:*

4.7.1 A full barrier hurdle test is defined as: the user begins by standing behind a start/end location, walks to the hurdle apparatus, steps over the hurdle, walks past the end marker or repeats the task if more barrier hurdles are included, traversing successive hurdles, and walks past the end marker.

4.7.2 A phased barrier test can include one or more phases of the full barrier test as follows, beginning with the user standing behind a start/end location:

4.7.2.1 *Phase 1*—The user walks to the barrier hurdle apparatus,

4.7.2.2 *Phase 2*—The user traverses the hurdle,

4.7.2.3 *Phase 3*—The user walks past the end marker or repeats phases 1 and 2 if more barrier hurdles are included, traversing successive hurdles, and walks past the end marker.

4.8 *Platform Hurdle Test:*

4.9 A full platform hurdle test is defined as: the user begins by standing behind a start/end location, walks to the hurdle apparatus, steps onto the platform hurdle, steps across the

[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 American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

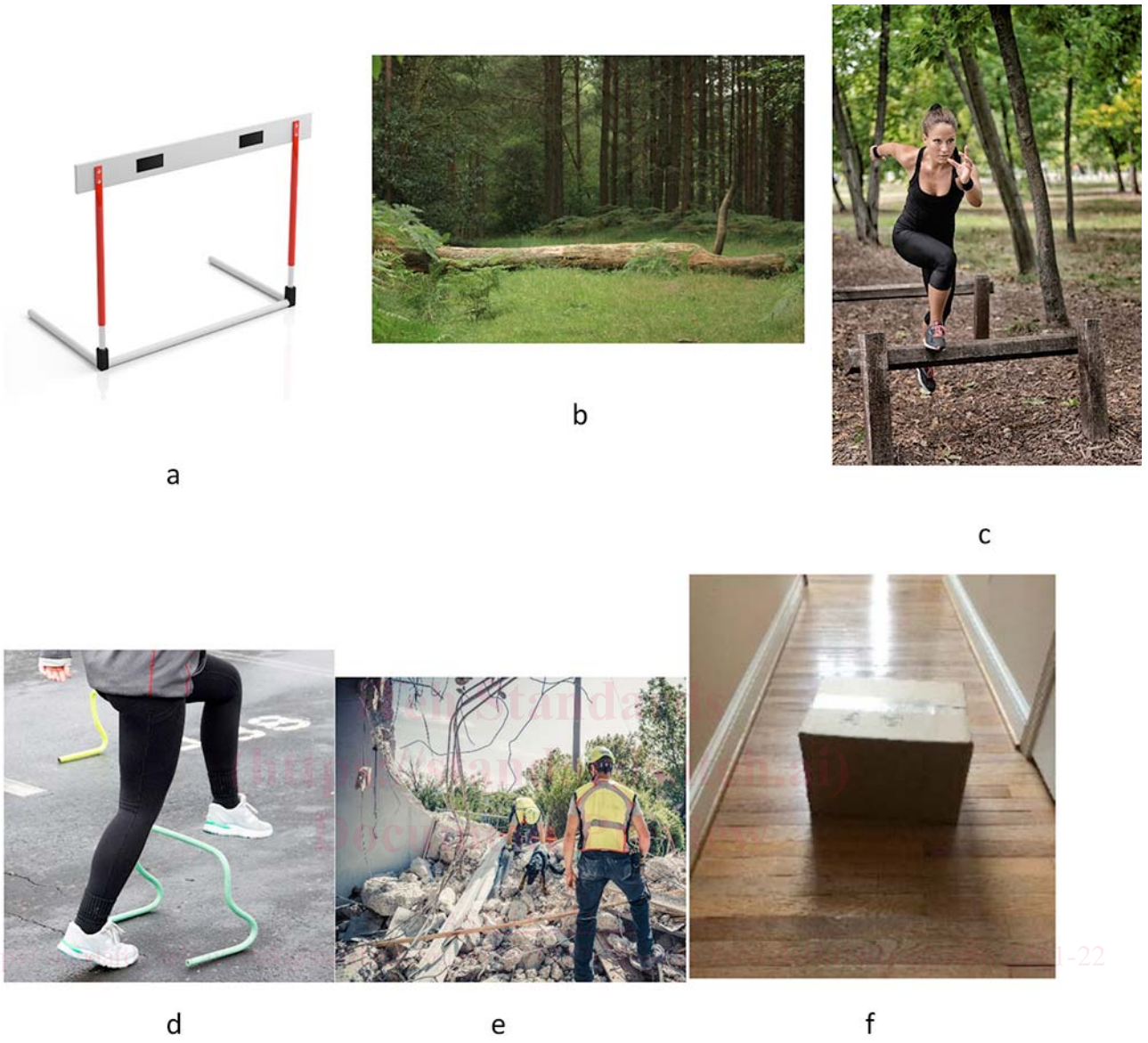


FIG. 1 Example Hurdles:
(a) Athletic Hurdle; (b) Log in the Forest; (c) High Step Over Hurdles used in an Obstacle Course; (d) Obstacle in a Path during a Rehabilitation Test; (e) Rubble Pile Obstacles to Climb/step Over by Response Workers; and (f) a Box Left in a Walkway

platform or turns around on the platform 180°, steps down from the platform onto the floor, and repeats the task if more platform hurdles are included, traversing successive hurdles past the start or end marker.

4.9.1 A phased platform test can include one or more phases of the full platform test as follows, beginning with the user standing behind a start/end location:

4.9.1.1 *Phase 1*—The user walks to the platform hurdle apparatus,

4.9.1.2 *Phase 2*—The user steps onto the platform hurdle,

4.9.1.3 *Phase 3*—The user performs either Phase 3a or Phase 3b:

(1) Phase 3a—The user steps across the platform to the opposite side.

(2) Phase 3b—The user rotates 180°.

4.9.1.4 *Phase 4*—The user steps down from the platform hurdle,

4.9.1.5 *Phase 5*—The user walks past the start/end marker or repeats phases 1 through 4 if more platform hurdles are included, traversing successive hurdles, and walks past the start/end marker.

4.10 The test requestor shall provide to the test administrator prior to the test, whether a full test or phased test will be considered the 'hurdles test' and, if a phased test is requested, the phase numbers of the barrier or platform, or both, phases to be tested.

4.11 The exoskeleton's capability is defined as the exoskeleton's ability to complete the hurdles test, where the user is capable of performing the task at the associated effective speed

and stability. Further, the test requestor can specify the statistical reliability and confidence levels of such a capability and thus, dictate the number of successful task performance repetitions that are required. In such a case, the average effective speed shall be used, instead, as the exoskeleton-user's capability. In either case, the resulting effective speed is specified as the exoskeleton-user's sustained speed.

4.12 The user is allowed to practice before the test. She/he is also allowed to abstain from the test before it is started. Once the test begins, there shall be no verbal communication between the user and the administrator regarding the performance of a test repetition, other than instructions on when to start and notifications of faults, and any safety-related conditions. The user shall have the full responsibility to determine whether and when they are uncomfortable with completing the test, and notify the test supervisor accordingly. However, it is the administrator's authority to judge the completeness of the repetition. Additionally, while it is the user's responsibility to alert the test supervisor of a safety issue they experience, the test supervisor should also alert the user to pause/stop the test if there are observable safety concerns (for example, too many falls, equipment malfunction, heart rate exceeds recommended heart rate for user's age (**1**)).[4]

NOTE 2—Practice using the test apparatus could help establish the applicability of the exoskeleton for the given test method. It allows the operator to gain familiarity with the apparatus and environmental conditions. It also helps the test administrator to establish the initial apparatus setting for the test when applicable.

4.13 The test requestor has the authority to select the height(s) of the hurdles for the specified hurdle apparatus. The test requestor also has the authority to select test methods that constitute the test event, to select one or more test site(s) at which the test methods are implemented, to determine the corresponding statistical reliability and confidence levels of the results for each of the test methods, and to establish the participation rules including the testing schedules and the test environmental conditions. As such, variations to this test method are also described in this standard, including:

4.13.1 Traversing hurdles while carrying a load(s); and

4.13.2 Environmental conditions including, for example, ground surfaces that are hard or soft, dry or wet; temperatures and humidity levels that are normal or extreme; precipitation that is no, low, or high.

5. Significance and Use

5.1 Hurdle designs can vary greatly in, for example: hurdle geometry, surface coatings, and coverings for a variety of industries. Fig. 1 shows examples of various hurdles.

5.2 Exoskeletons are being used in the industrial/occupational, military, response, medical, and recreational sectors to enhance safety and effectiveness of the user to perform tasks. Hurdles are used in many tasks performed and may include, for example, upper, lower, or full body movement in order to complete the task. For example, an exoskeleton may be used to help rehabilitate a patient who suffered a traumatic injury. And in manufacturing, warehousing, and other occupations, and other similar environments, workers in exoskeletons may traverse hurdles (for example, obstacles) in the walkways while carrying or not carrying loads, indoors or outdoors, as part of their daily activities. The testing results of exoskeletons shall describe, in a statistically significant way, how reliably the exoskeleton is able to support tasks within the specified types of environments, confinements, and terrains, and thus provide sufficiently high levels of confidence to determine the applicability of the exoskeleton.

5.3 This test method addresses exoskeleton safety and performance requirements expressed by manufacturing, emergency responders, military, or other organizations requesting this test. The safety and performance data captured within this test method are indicative of the test exoskeleton's and the exoskeleton user's capabilities. Having available direct information from tested exoskeleton(s) with associated performance data to guide procurement and deployment decisions is essential to exoskeleton purchasers and users.

5.4 The testing results of the candidate exoskeleton(s) shall describe, in a statistically significant way, how reliably the exoskeleton user is able to negotiate hurdles. The test apparatus described in Section 6 is intended to be a single or set of hurdles where repeatable results between exoskeletons, users, and organizations are comparable. The standard test setup and apparatus can also be used to support training and establish proficiency of exoskeleton users, as well as provide manufacturers with information about the usefulness of their exoskeleton(s) for tasks.

5.5 Although the test method was developed for the sectors listed in 5.2, it may be applicable to other operational domains.

6. Test Course and Apparatus

6.1 The actual performance space where the exoskeleton is to be used or apparatus of which will be used, or both, as exemplified in Fig. 1 and Fig. 2, may be used for this test. In the event that the actual performance space or apparatus, or both, is not available or the test is to be exactly replicated by others, or both, test setup and standard hurdles test apparatus' are also described in this section.

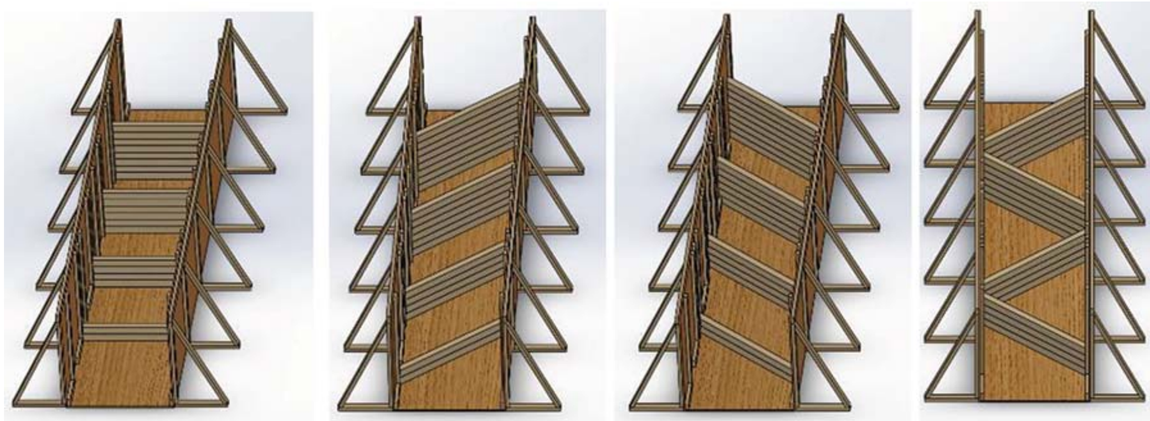
6.2 *Optional Equipment:*

6.2.1 *Safety equipment,* for example: belay; gait belt; personal protective equipment, such as: knee pads, helmet, gloves; user health monitoring equipment, such as: pulse oximeter, oxygen source, Borg Breathlessness Scale, sphygmomanometer, inertial measurement units, joint angle and speed measurement equipment; and other safety equipment, such as: telephone, automated electronic defibrillator that can be at the ready as needed.

6.2.2 *User measurement devices,* for example: walkway or force plates for traversing hurdles analysis; step or railing, or both, force/contact measurement/detection devices, user tracking system; heart rate, pulse, oxygen monitors.

6.2.3 *Loads,* for example: tools, crates, bags (refer to Practice F3443).

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



a b c d

FIG. 2 Barrier Hurdles Test Apparatus:
(a) Straight Barriers, (b) Angled, Aligned-left, (c) Angled, Aligned-right Barriers, and (d) Angled, Alternating Barriers

6.3 The test course shall include START markings near the hurdle apparatus.

6.4 *For a Phased Barrier Test,* the following additional parameters shall be set prior to the test:

6.4.1 *Phase 2*—If no Phase 1, the location where the user begins the test to traverse a hurdle(s),

6.4.2 *Phase 3*—The location of end marker or the location where the user turns around 180°, or both,

6.5 *For a Phased Platform Test,* the following additional parameters shall be set prior to the test:

6.5.1 *Phase 2*—If no Phase 1, the location where the user begins the test to traverse a hurdle(s),

6.5.2 *Phase 3b*—The location, if needed, where the user turns around 180°,

6.5.3 *Phase 5*—The location of the end marker which may be the same as the start marker.

6.6 Turn-around space for the user to reverse direction shall be provided according to the apparatus being used. A starting and ending line, which marks the START and END of the test repetition, should be marked on the floor using brightly colored tape.

6.7 *Required Apparatus:*

6.7.1 1 m or greater, straight unimpeded path to the hurdle apparatus,

6.7.2 *Hurdle Apparatus*—one or more barrier or platform, or both, hurdles,

6.7.3 *Timer (for example, stopwatch),* with at least 0.1 s calibrated time resolution,

NOTE 3—Other time-synchronized tools are: clock synchronized to WWVB radio or computer-based timing synchronized to network time protocol.

6.7.4 Repetition counter,

6.7.5 Tape or similar marking (preferably bright colored), and

6.7.6 Test report (see Section 10).

6.8 *Standard Hurdles Test Apparatus:*

6.8.1 A standard hurdles test apparatus is suggested for use to provide maximum repeatability in test result comparison between testing organizations, users, or exoskeletons, or any combination thereof. The standard hurdles test apparatus' are shown in Fig. 2 and Fig. 3 and are designed based on readily accessible materials. The apparatus dimensions are detailed in Appendix X2.

6.8.2 A standard hurdles test apparatus is to be constructed from nominal 2 by materials made from SPF (spruce, pine, fir) wood, oriented strand board (OSB) standard, appropriately sized fasteners, and can be weighted down using weights or fixtured to the floor or ground surface, to minimize apparatus movement.

6.8.3 The barrier hurdle apparatus may be constructed as barriers aligned perpendicular to the user traversal path as in Fig. 2a or angled to the user traversal path as in Fig. 2b or Fig. 2c, or combinations thereof. If angled, the barrier shall be 45° to the user traversal path. The barrier shall be stackable 2 by materials allowing 3.8 cm (1.5 in.) height variations.

6.8.4 The platform hurdle apparatus shall be constructed as in Fig. 3. The platform heights shall be stackable and made from nominal 2 by material (that is, 2 by 4 or 4 by 4 SPF) framing with 1.9 cm (¾ in.) OSB decking on top totaling approximately 10 cm (4¼ in.) height variations.

6.8.5 Standard railings may be added to the apparatus as needed.

6.9 *Alternative Hurdles Apparatus:*

6.9.1 Any alternative apparatus design, such as for increased platform loading, increased or decreased sizing, alternative materials (for example, other woods, metals, composites, and combinations thereof), shall be engineered as needed to safely and effectively support the required test.

6.9.2 Smaller turn-around space, including smaller platform hurdles, located at the start/end location, is a potential challenge to exoskeletons. Smaller turn-around space(s) shall be engineered as needed to safely and effectively support the required test. If smaller turn-around space is provided in actual

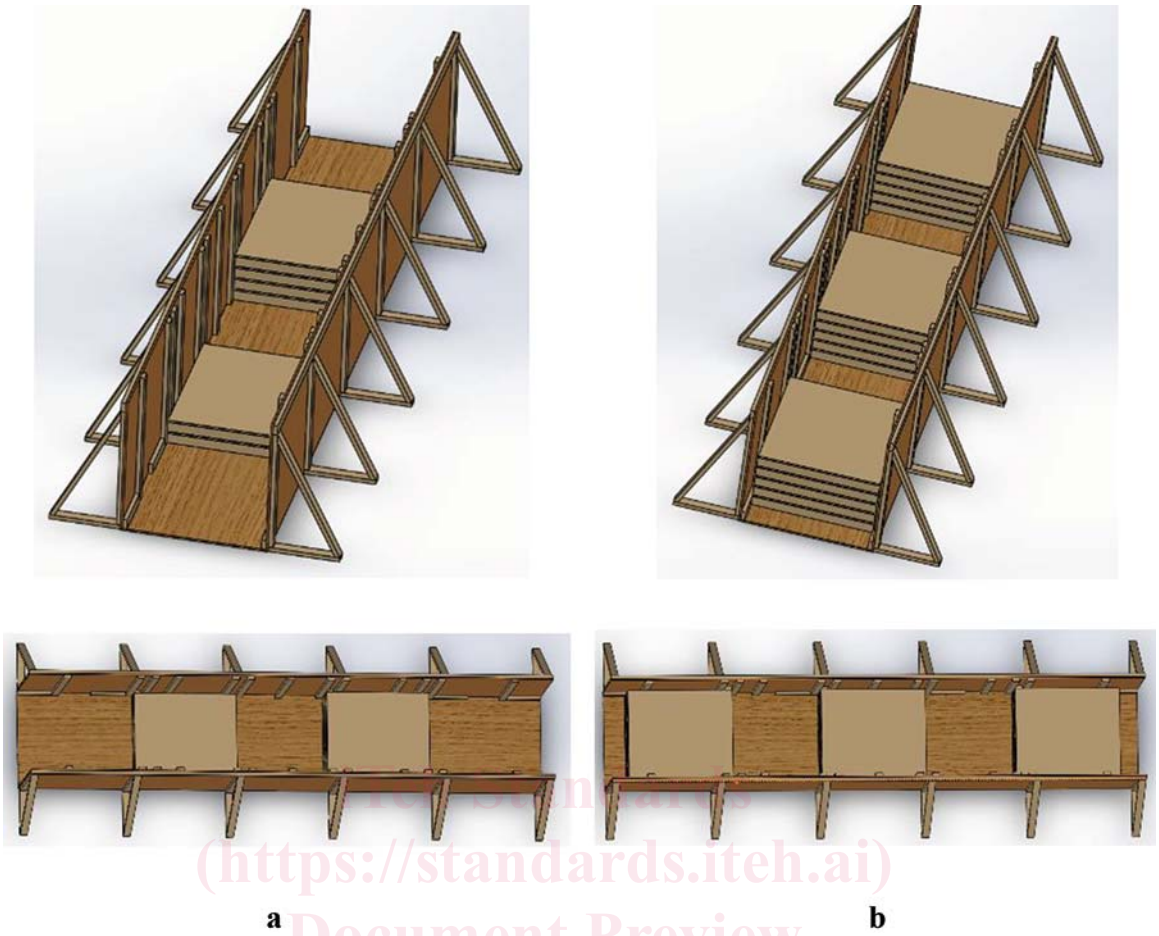


FIG. 3 Platform Hurdles Test Apparatus Isometric and Top Views showing (a) Two and (b) Three Platforms

apparatus settings (that is, not designed and constructed), appropriate safety precautions and test safety shall be used. See also Test Method F3523.

6.9.3 Larger hurdle widths may be required, as with larger exoskeletons or medical hurdle traverse applications, where additional equipment or a test technician, safety operator, etc., or combinations thereof, may traverse with or beside the exoskeleton user. As such, the actual in situ hurdle apparatus to be used shall accommodate space to allow an exoskeleton user and the additional equipment or test technician, or both, as well as any associated safety, measurement, etc. equipment to perform the test without hindrance due to space limitations. If a larger hurdle width apparatus is to be designed, constructed, and used, the apparatus shall be engineered as needed to safely and effectively support the required test.

6.9.4 A single or multiple (as shown in Fig. 2 and Fig. 3) hurdles may be used for the test apparatus. If additional hurdles are designed, constructed, and used, the apparatus shall be engineered as needed to safely and effectively support the required test. For example, the hurdles spacing between one another.

6.10 The test course layout for a full test is shown in Fig. 4 and, for consistency throughout this test method, illustrates the use of the standard test apparatus. If a phased test is requested, see also 6.4 through 6.9 for additional phased test information.

7. Hazards

7.1 Hazards for hurdles tests when using exoskeletons can be as follows: slips, trips, falls, fatigue, and collisions dependent upon the user and exoskeleton, the test environment (for example, lighting, moisture), and the apparatus (for example, high hurdles). Emergency egress from the area and apparatus should also be considered. Safety equipment should be considered to be used during the test (for example, belay, gait belt). Refer to (**1-3**) in order to characterize biomechanical stressors. Note that although these references address typical risks and mitigation procedures, they may not address safety issues for an exoskeleton user.

7.2 Safety standards providing risks and mitigation procedures for hazards when using an exoskeleton are developed or being developed, including:

7.2.1 ISO 13482; and

7.2.2 Guide F3527.

8. Calibration and Standardization

8.1 The exoskeleton configuration as tested shall be described in detail on the test form, including all subsystems and components and their respective features and functionalities, including version or iteration details as applicable. The configuration shall be subjected to all the test suites, as defined in

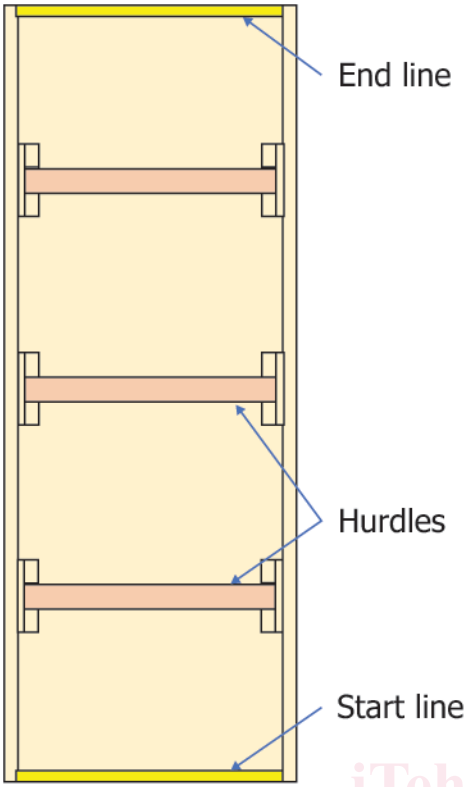


FIG. 4 Full Test Layout (Top View) using Example Straight Barrier Hurdles

3.2.3, as appropriate. Any variation in the configuration shall cause the resulting exoskeleton variant to be retested across all the test suites to provide a consistent and comprehensive representation of the performance.

8.2 Once an exoskeleton user begins a test, by starting to execute the task as specified in 4.1, the exoskeleton shall be used to perform the task for the specified number of repetitions through completion without changing the exoskeleton or apparatus.

8.3 A battery may be changed or charged between repetitions provided that other configurations remain unaltered, and if allowed by the test requestor. Unless otherwise stated by the requestor, during the test the exoskeleton shall not be allowed to have the energy/power source replenished nor shall the exoskeleton be allowed any human physical intervention, including adjustment, maintenance, or repair. Any such actions shall be considered a fault condition and the test should be restarted from the beginning.

8.4 The metric for this test method is the complete and successful hurdles test, as set by the test requestor and outlined in this test method, for the specified number of continuous repetitions. In addition, the elapsed time for the user to successfully complete the hurdles test is a performance proficiency index reflecting the combination of the exoskeleton's capability and efficiency, and the user's skill level. Therefore, this temporal aspect is a part of the test and the results shall be recorded on the test form. The average speed is specified as the sustained speed. Metrics shall also include any test anomalies or occurrences, such as: stumbles, trips, falls, rests, variation in traversing hurdles throughout the test or from baseline (that is, no exoskeleton used called NoEXO) to exoskeleton test (exoskeleton is used called EXO).

8.5 The test requestor has the authority to specify the environmental variables, which may affect the test results. All environmental settings shall be documented using Practice F3427.

8.6 The test requestor has the authority to specify the number of repetitions required for the test. Considerations for user fatigue, abilities, exoskeleton capabilities, and other characteristics that may impact the tests shall be considered. Extending the duration of the test (for example, perform the full hurdles test four times over eight hours, separated by two-hour rests, for several days and several weeks to achieve 30 repetitions) may also be included in the overall test confidence and shall be noted on the test report. Guidance on reliability of test data given the number of repetitions is provided in Appendix X1.

9. Procedure

9.1 A test requestor requests a full or phased hurdle test, including all test parameters (for example, test apparatus, environment, exoskeleton configuration, etc.) to be recorded and documented.

9.2 For all tests, the environmental conditions of the space where the test will be performed shall be documented using Practice F3427, allowing test repeatability.

9.3 The exoskeleton configuration is documented in full detail to ensure that repeatable tests can occur. Upon publication and to ensure standardized documentation, Practice F3613 and Practice for Recording the Exoskeleton Test Configuration[5] shall be used to record the exoskeleton configuration.

9.4 If a load (for example, tool, equipment, artifact load) is to be handled during the test, document the artifact or real load using Practice F3443.

9.5 If any movement by the user is requested in addition to this test (for example, move through an area or maze prior to traversing the hurdle apparatus), the test administrator should document in detail the movement for repeatable testing (for example, Practice F3517, and Test Method F3523 or Test Method F3528, or both).

9.6 *User Preparation:*

9.6.1 The user should wear the appropriate, comfortable clothing and shoes for walking in the chosen test environment. Also, the exoskeleton user should use the appropriate walking aids normally needed by the user or for the test, or both (cane(s), etc.).

9.6.2 The user should not have exercised vigorously within 2 h of beginning the test, unless requested by the test requestor (for example, for a fatigue test). Prior to the test, the amount of

[5] Standard designation for this practice is to be added after the standard is approved and published.