Designation: F3584 – 22

Standard Test Method for Exoskeleton Use: Obstacle Avoidance: Walking[1]

This standard is issued under the fixed designation F3584; 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, when avoiding obstacles.

1.1.2 Exoskeletons shall 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.

1.1.3 Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to avoid obstacles while walking, as intended by the user or test requestor, while using an exoskeleton is essential for exoskeleton deployment for a variety of tasks (for example, ascending/descending stairs, crossing gaps and hurdles, balancing on a beam). This test method specifies test setup, procedure, and recording to standardize this obstacle avoidance task for testing exoskeleton user movement.

1.1.4 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; avoiding obstacles, on various types of floor surfaces or terrains, or within confined spaces, or combinations thereof. Standard test methods are required to evaluate whether or not exoskeletons meet these requirements while also allowing test repeatability.

1.1.5 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 obstacle avoidance 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.

1.1.6 The test methods quantify elemental exoskeleton use capabilities necessary for sector applications listed in 1.1.2 and perhaps other applications. 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 weigh 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 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 obstacle avoidance while walking and the test requestor intends to use the exoskeleton to perform an obstacle avoidance test (for example, for research, development of obstacle avoidance-capable use by a manufacturer, training as in military 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 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 February 2023. DOI: 10.1520/F3584-22.

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]

F3200 Terminology for Robotics, Automation, and Autonomous Systems

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 available in Terminology F3323. Terminology specific to this standard are 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 *obstacle, n*—static or moving object that obstructs the intended movement. **[F3200]**

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 use: obstacle avoidance: walking," is defined as the exoskeleton-user performing an obstacle avoidance test, including a number of repetitions as set by the test requestor. The test includes only stationary objects to avoid and covers all forms of obstacle avoidance while walking: agility, step-over, side-step, walk-around, and duck-under. Guidance on number of repetitions for the test is shown in Appendix X1. In-situ obstacles (for example, boxes, trees, logs) can be used for this test method. For ideal test replication, standard obstacle avoidance test apparatuses (for example, foam blocks, 2 by 2 nominal wooden bars, cloth and post crowd control) can be used for this test method. See Fig. 1 for an illustration.

4.2 The test is described as follows:

4.2.1 This test can be used to assess aerobic function, endurance, obstacle avoidance capability and speed, balance, or other parameters, or combinations thereof, as required by the test requestor.

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

4.2.2.1 Completion of the full or phased test;

4.2.2.2 Number of obstacles avoided;

4.2.2.3 Completion time;

4.2.2.4 Change(s) in user (for example, heart rate, fatigue, toe drag) by a specified amount;

4.2.2.5 Balance, stability, missed steps, near falls/falls (measures of dynamic balance can include, for example, Lyapunov exponents, center-of-mass displacement, multivariate multiscale entropy, normalized jerk, and peak-to-peak angular torso momentum);

4.2.2.6 Contact with obstacles;

4.2.2.7 Changes between the baseline (that is, called No-EXO when no exoskeleton is used) versus while using the exoskeleton (that is, called EXO when an exoskeleton is used);

4.2.2.8 Clearance from obstacle; and

4.2.2.9 Variability in the distribution of minimal clearance.

4.3 For all tests, the specified START point to the END point and 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 6.

4.4 A full obstacle avoidance: walking test is defined as: the user begins by standing behind a start marker, walks while avoiding obstacles in the agility apparatus, turns around 180° after passing a turn marker, walks while avoiding obstacles in the agility apparatus again, walks to the continue/end marker, traverses the step-over apparatuses, continues to the barriers and side-steps through the left side of the barriers, walks around the barriers, walks while ducking under the height bar past the turn marker, again ducks under the height bar, walks around and side-steps again through the right side of the barriers, walks around and continues to traverse again through the step-over apparatuses, and crosses the end line to complete the test. A phased test includes portions of the full test as follows:

Phased Obstacle Avoidance Test

4.4.1 *Phase 1*—The user begins by standing behind a start marker, walks while avoiding obstacles in the agility apparatus,

[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.

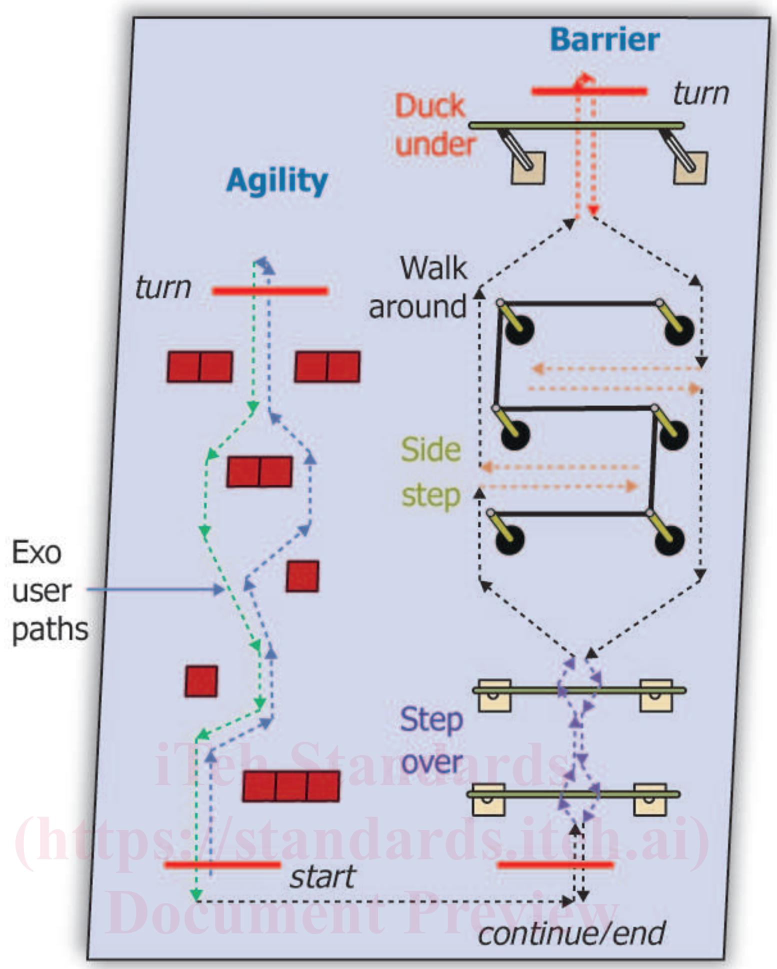

FIG. 1 Graphic of the Obstacle Avoidance Test Apparatus showing the Exoskeleton User Paths for Each User Movement and the Start, Turn, and End Lines

4.4.2 *Phase 2*—Turns around 180° after passing a turn marker,

4.4.3 *Phase 3*—Walks while avoiding obstacles in the agility apparatus again,

4.4.4 *Phase 4*—Walks to the continue/end marker,

4.4.5 *Phase 5*—Traverses the step-over apparatuses,

4.4.6 *Phase 6*—Continues to the barriers and side-steps through the left side,

4.4.7 *Phase 7*—Walks around the barriers,

4.4.8 *Phase 8*—Walks while ducking under the height bar past the turn marker,

4.4.9 *Phase 9*—Again, ducks under the height bar,

4.4.10 *Phase 10*—Walks around and side-steps again through the right side of the barriers,

4.4.11 *Phase 11*—Walks around the post and tape apparatus, and

4.4.12 *Phase 12*—Traverses again through the step-over apparatuses and crosses the end line.

4.5 The test requestor shall provide to the test supervisor prior to the test, whether a full test or phased test will be considered the 'obstacle avoidance test' and, if a phased test is requested, the phase numbers of the 12 Phases to be tested.

4.6 The test requestor shall provide to the test supervisor prior to the test, exoskeleton information (for example, age, prior use, etc.), user experience, and practice time length and activity.

4.7 The exoskeleton's capability is defined as the exoskeleton's ability to complete the obstacle avoidance test where the user is capable of performing the task at the associated effective speed, stability, or other associated parameters, or combinations thereof, as required by the test requestor. 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.

4.7.1 Guidance on the number of repetitions for a discrete, binary variable test is provided in Appendix X1 (that is, complete the test vs. failure to complete the test). If choosing

the number of repetitions for continuous variable (for example, speed, distance) tests, consideration should include: variability between subjects, user capability to perform the test, etc.

4.8 The durability of the exoskeleton shall be such that it can withstand the obstacle avoidance test requirements without failure, as specified by the manufacturer.

4.9 The user is allowed to practice before the test and if practice occurs, practice time, activity, and other pertinent information shall be documented in the notes section on the test report as practice can change the user. If practice occurs for one subject, all subjects completing the test shall practice for the same time and activity. The user is also allowed to abstain from the test before it is started.

4.10 Once the test begins, there shall be no verbal communication between the exoskeleton user and the test supervisor regarding the performance of a test repetition, other than instructions on when to start, 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 test supervisor'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 could help establish the applicability of the exoskeleton for the given test method. It allows the operator to gain familiarity with the standard setup, procedure, apparatus, and environmental conditions. It also helps the test supervisor to establish the initial setup, procedure, including both the user and testing personnel, or apparatus setting for the test, or combinations thereof, when applicable.

4.11 The test requestor has the authority to select the parameters that may affect the user for the obstacle avoidance task. 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 (see 9.6), including obstacle avoidance while/with:

4.11.1 Carrying a load(s);

4.11.2 Various 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;

4.11.3 Various obstacle heights for step-over, duck-under;

4.11.4 Various obstacle sizes made from a grid of obstacles;

4.11.5 Various width between side-stepped obstacles;

4.11.6 Added load handling (for example, evenly distributed load, uneven load);

4.11.7 Greater than 1× comfortable gait speed;

4.11.8 Distractions (for example, time pressure, visual, mental, occluded vision, with/without load handling); and

4.11.9 Walking backward.

5. Significance and Use

5.1 Obstacles can vary greatly in, for example: length, width, height, quantity, geometry, and for a variety of industries. Fig. 2 shows examples of various obstacles.

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. Many tasks involve avoiding obstacles, and may include for example, upper, lower, or full body movement in order to complete the task. As there are infinite obstacles and ways that obstacle courses can be designed, this test method addresses obstacle avoidance while walking through a standard set of obstacles. Dependent upon the task, it may require people to traverse various environmental conditions (for example, ground) and avoid obstacles while wearing an exoskeleton. For example, an exoskeleton may be used to help during construction or in medical facilities where workers in exoskeletons avoid obstacles with and without carrying loads as part of their daily activities. In military, manufacturing, and response areas, exoskeleton users may for example, step over or under, side-step between, or walk around obstacles, or combinations thereof, to perform the task at hand. Variations to obstacle avoidance may include, for example, increased user speed/momentum, load handling, and distractions that may change user performance when avoiding obstacles. The testing results of exoskeletons shall describe, in a statistically significant way (see guidance in Appendix X1), 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 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 avoid obstacles while walking. The test apparatus described in 6.7 is intended to be a single obstacle layout 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. For guidance on exoskeleton training, see Practice F3444/F3444M.

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

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

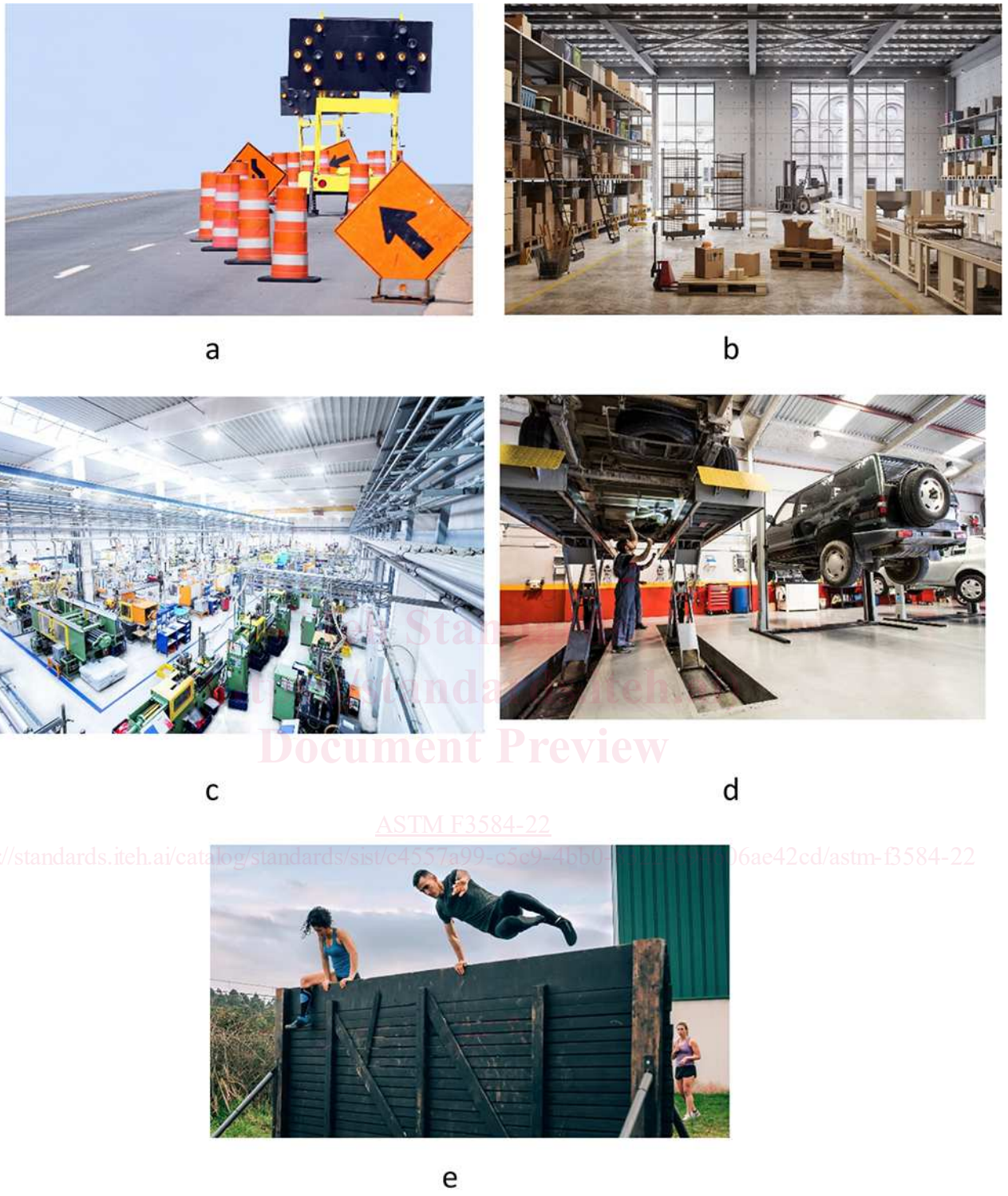

FIG. 2 Example Obstacles in: (a) Road Construction; (b) Warehouse; (c) Manufacturing: Floor; (d) Manufacturing: Overhead; (e) Military Obstacle Course

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. 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, the standard test setup and apparatus are 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, 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 or automated electronic defibrillator that can be at the ready as needed.

6.2.2 *User measurement devices,* for example: walkway or force plates for obstacle avoidance analysis; step force/contact measurement/detection devices, user tracking system; heart rate, pulse, oxygen monitors, inertial measurement units, or joint angle and speed measurement equipment.

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

6.3 The test course shall include start, turn, and end markings as part of the obstacle avoidance apparatus.

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

6.5 The use of exercise equipment (for example, treadmill with automatic moving obstacles) is not recommended to replace the obstacle avoidance apparatus for this test method as users are unable to pace themselves on such equipment. Exercise equipment test results, therefore, are not interchangeable with obstacle avoidance apparatus tests.

6.6 *Required Apparatus:*

6.6.1 1 m or greater straight, unimpeded path to and from the obstacle avoidance apparatus,

6.6.2 *Obstacle Avoidance Apparatus* (see Fig. 1 and Appendix X2),

6.6.3 *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.

6.6.4 *Repetition Counter,*

6.6.5 *Tape or Similar Marking* (bright colored), and

6.6.6 *Test Report* (see Section 10).

6.7 *Obstacle Avoidance Test Apparatus (if used):*

6.7.1 A standard obstacle avoidance test apparatus is suggested for use to provide maximum repeatability in test result comparison between testing organizations, users, or exoskeletons, or combinations thereof. The standard obstacle avoidance test apparatus is shown in Fig. 3 and is designed based on nominal lumber size and materials. The apparatus dimensions are detailed in Appendix X2.

NOTE 4—Space permitting, the agility and barrier portions of the test apparatus may be aligned (that is, not side-by-side) with associated turn and end line markings as shown in Fig. 1.

6.7.2 A standard obstacle avoidance test apparatus is to be constructed from readily available and nominal 2 by materials made from SPF (spruce, pine, fir) wood, standard and appropriately sized fasteners, and can be weighted using weights or fixtured to the floor or ground surface to minimize apparatus movement. The base, shown in Fig. 3, is intended to only show

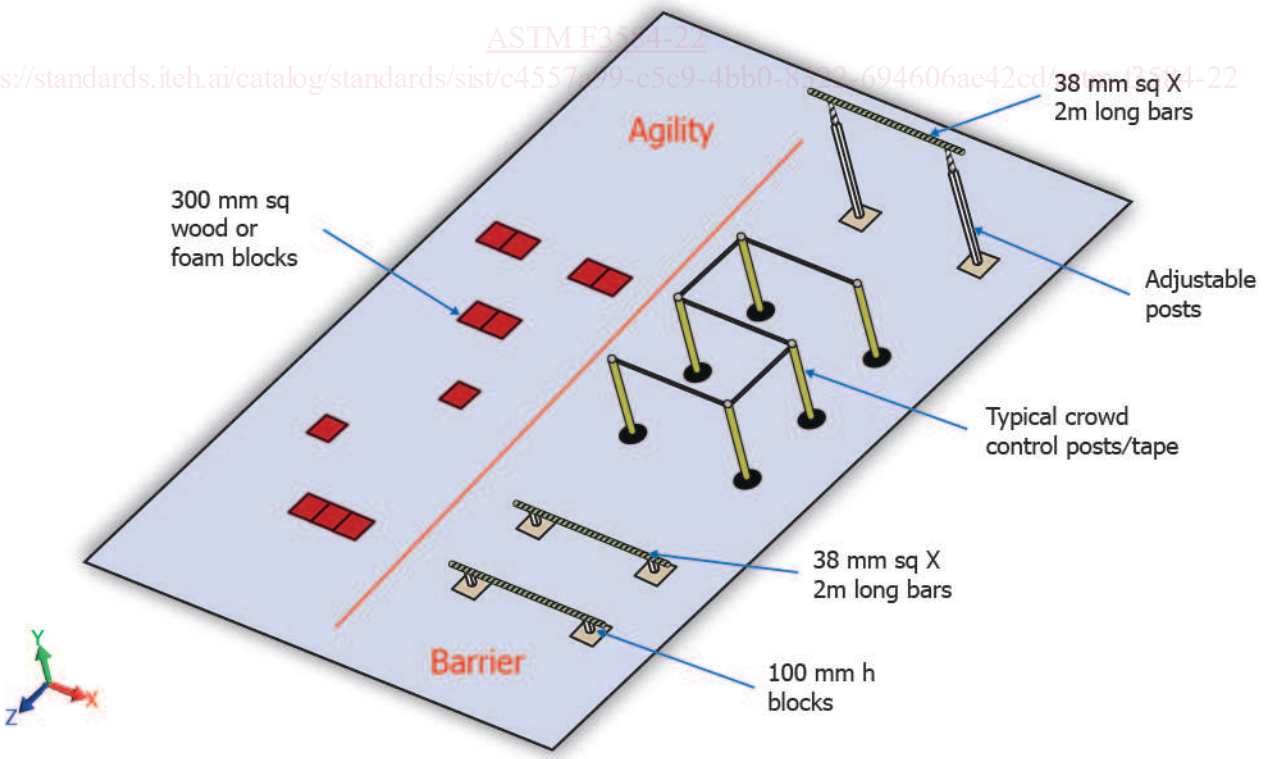

FIG. 3 Obstacle Avoidance Test Apparatus

a ground surface and the estimated space required for layout of the obstacle avoidance test apparatus.

6.7.3 The standard obstacle avoidance test apparatus can be described in parts as follows:

6.7.3.1 The agility apparatus (Fig. 3 left side) includes 300 mm square wood or foam blocks, spaced as shown in Appendix X2.

6.7.3.2 The barrier apparatus (Fig. 3 right side) includes:

(1) Step-Over Apparatus—Two pairs of 100 mm high 2 by 4 blocks fastened to 4.7 cm square bases, separated 1.5 m with a bar (38 mm square by 2 m long) made of wood or other lighter material resting on top.

(2) Side-Step and Walk Around Apparatus—Typical crowd control posts/tape or other similar devices (for example, tall hazard cones and tape).

(3) Duck-Under Apparatus—Two square wood, plastic, or metal tubes with 13 mm diameter holes through two sides and spaced 10 cm vertically along the tube. The tubes are spaced 1.5 m apart. Two 38 mm square by 100 cm long bars are inserted into the tubes' tops and supported in height (between 100 cm and 150 cm) using a 13 mm diameter by 15 cm long dowel inserted into the tubes' side holes at the same height for both tubes. A bar (38 mm square by 2 m long) made of wood or other lighter material rests on top of the square bar ends.

6.8 The test course layout for a full test is shown in Fig. 1 and, for consistency throughout this test method, illustrates the use of the standard test apparatus.

7. Hazards

7.1 Hazards for obstacle avoidance tests when using exoskeletons can be as follows: slips, trips, falls, fatigue, and collisions dependent upon the exoskeleton, the test environment (for example, lighting, moisture), and the apparatus (for example, bars, blocks, posts). 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 (**2-4**) in order to characterize biomechanical stressors.

NOTE 5—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 have been 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 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 Section 4, 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 shall be restarted from the beginning.

8.4 The metric for this test method is the complete and successful obstacle avoidance test, as outlined in this test method, for the specified number of continuous repetitions, as set by the test requestor. In addition, the elapsed time for the user to successfully complete the obstacle avoidance 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. Metrics shall also include any test anomalies or occurrences, such as: stumbles, trips, falls, rests, variation in step-over or duck-under bars throughout the test or from baseline (that is, no exoskeleton used, called NoEXO) to exoskeleton test (exoskeleton is used, called EXO). Test anomalies or occurrences shall be noted on the test report and may also provide additional statistical importance to the test requestor.

8.5 The test requestor has the authority to specify the environmental variables, which may affect the test results. All environmental conditions 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 test should not occur unless under rare circumstances (for example, rehabilitation, mean-time-between-failure tests over many days). 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 obstacle avoidance 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