



Designation: F3528 – 21

Standard Test Method for Exoskeleton Use: Gait¹

This standard is issued under the fixed designation F3528; 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 reappraisal. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reappraisal.

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 gait.

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. Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to walk, as intended by the user or test requestor, while using an exoskeleton is essential for exoskeleton deployment for a variety of tasks. This test method specifies test setup, procedure, and recording to standardize this gait task for testing exoskeleton user movement.

1.1.3 Exoskeletons shall be able to handle many types of task and terrain complexities. The required movement capabilities include, for example: walking, running, crawling, climbing, traversing gaps, hurdles, stairs, slopes, various types of floor surfaces or terrains, and confined spaces. 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 gait 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. Not all exoskeletons may have the capabilities needed to use this test method.

1.1.5 This test method tests for generic gait exoskeleton capability, with straight paths and no test course curves, obstacles, or other complexities not described herein (see 4.6). This test method is considered the basis for exoskeleton gait capability testing.

1.1.6 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 *Performing Location*—This test method shall be performed in a testing laboratory or at a site that represents the place where the exoskeleton will be used.

1.3 *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.

1.4 *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.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

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.

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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
- F3517** Practice for Movement Tests When Using an Exoskeleton
- F3527** Guide for Assessing Risks Related to Implementation of Exoskeletons in Task-Specific Environments

2.2 Other Standards:

- ISO 13482** Robots and robotic devices — Safety requirements for personal care robots³

3. Terminology

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

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 *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 walking, is defined as the exoskeleton-user performing all three of the following tests: (1) 6 minute walking test (6MWT) **(1)**⁴; (2) 10 meter walking test (10MWT) **(2)**; and (3) timed up and go (TUG) test **(3)**. The tests are described as follows:

4.1.1 **6MWT**—This test is used to assess aerobic capacity and endurance, where the distance covered over a time period of 6 min is used as the outcome. The user begins at a START point specified by the test supervisor and ends when the test supervisor has timed 6 min. Two points, START and TURN, are spaced (for example, 30 m apart) for the user to walk and turn about such that the user continuously walks for 6 min between the two points.

4.1.2 **10MWT**—This test is used to assess functional mobility, walking speed, and balance over a short distance. The user begins at a START point and ends at an END point spaced

10 m apart, both specified by the test supervisor. Two additional lines are placed at 2 m and 8 m from the start line to allow measurement of the user's steady state velocity between the two lines.

4.1.3 **TUG**—This test is used to assess fall risk and measure the progress of balance, sit-to-stand, and walking. A full TUG test (see **9.20**) can be performed as a single test in its entirety where the user begins by sitting in a chair, stands when the test supervisor directs the user to begin the test, walks three (3) meters, turns around 180°, walks back to the chair, turns back around 180°, and sits in the chair. As some exoskeletons may not be able to perform a full TUG test, a phased TUG test (see **9.21**) can instead be performed. The phased TUG test divides the full TUG test into six independent phases where selected TUG test phases (for example, phases 1 and 2; phases 1 through 5), which shall be selected prior to the test by the test requestor, are to be performed by an exoskeleton user. The phased TUG test divides the full TUG test as follows:

4.1.3.1 *Phase 1*—Stand up from a chair (or from an alternative position from sitting (for example, kneeling) as set by the test requestor prior to the test);

4.1.3.2 *Phase 2*—Walk 3 m;

4.1.3.3 *Phase 3*—Turn around 180°;

4.1.3.4 *Phase 4*—Walk 3 m in the opposite direction from Phase 2;

4.1.3.5 *Phase 5*—Turn around 180°;

4.1.3.6 *Phase 6*—Sit down in a chair (or configure to an alternative position from sitting (for example, kneeling) as set by the test requestor prior to the test).

4.2 For all tests, the specified path from the START point to the END point, TURN point, or chair, as needed, shall be defined by the test requestor prior to the test. The required apparatuses are described in Section 6.

4.3 The exoskeleton's capability is defined as the exoskeleton's ability to complete the gait task, where the exoskeleton or user, or both, is capable of performing the 6MWT, 10MWT, and full or phased TUG tests, as set by the test requestor and can perform the test at the associated effective speed and stability. The average effective speed shall be used as the exoskeleton-user's capability and sustained speed.

4.4 The exoskeleton user is allowed to practice before the test.

4.5 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 and notifications of faults, and any safety related conditions. The user shall have the full responsibility to determine whether and when they have completed a repetition, and notify the test supervisor accordingly. However, it is the test supervisor's authority to judge the completeness of the repetition.

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, when applicable, or combination thereof.

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>.

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

4.6 The test requestor has the authority to select the parameters that may affect the user for the gait 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.

4.7 Variations to this test method are also described in this standard and can include, for example:

4.7.1 6MWT, 10MWT, or TUG while carrying a load(s);

4.7.2 TUG from a squat position instead of a chair;

4.7.3 Environmental conditions including, for example, ground surfaces that are level or undulating, 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 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. Gait is a component of many tasks that someone would do with an exoskeleton. For example, an exoskeleton may be used to help rehabilitate a patient who suffered a traumatic leg injury. In manufacturing, warehousing, military, and other similar environments, workers and soldiers in exoskeletons walk with and without carrying loads, many times over long distances, indoors or outdoors, as part of their daily activities. **Fig. 1** shows examples of exoskeleton users walking, which, depending upon the task, may require people to traverse various ground surfaces while wearing an exoskeleton. 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 to a given task.

5.2 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 for exoskeleton purchasers and users.

5.3 The standard test setup and apparatus (see Section 6) is specified to be easily fabricated to facilitate self-evaluation and replication of gait tests by exoskeleton designers, developers, manufacturers, and users. 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.

5.4 Although the test method was developed for the sectors listed in 5.1, 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 in-situ (that is, typically found in the environment, such as trees, loads, natural markings) apparatus of which will be used, as exemplified in **Fig. 1**, or both, may be used for this test. In the event that the actual performance space or the in-situ apparatus, or both, is not available or the test is to be exactly replicated by others, or both, test setups and the standard apparatus, as described in the following subsections, shall be used. Refer to **Fig. 2** for test course layouts.

6.2 Optional Equipment:

6.2.1 *Safety equipment*, for example: heart rate monitor, pulse oximeter, oxygen administration kit, sphygmomanometer, telephone, automated electronic defibrillator, and Borg breathlessness scale that can be at the ready as needed.

6.2.2 *User measurement devices*, for example: walkway (that is, pressure mats) or force plates for human gait analysis; user tracking system; heart rate, pulse, and oxygen monitors.

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

6MWT

6.3 The walking course shall be 30 m (98 ft) in length with at least 2 m beyond the course on both ends for turnaround space. The length of the course should be marked every 3 m. (A shorter corridor requires users to take more time to reverse directions more often, reducing the 6MWT.) The turnaround points at 30 m should be marked with a highly visible marker, such as an orange traffic cone. A starting line, which marks the START and END of each 60 m lap, should be marked on the floor using brightly colored tape.

6.4 The use of a treadmill is not recommended for the 6MWT as users are unable to pace themselves on a treadmill. Treadmill test results, therefore, are not interchangeable with corridor tests.

6.5 Required Apparatus:

6.5.1 34 m or greater straight, unimpeded corridor or path,

6.5.2 Countdown timer (or stopwatch),

6.5.3 Lap counter,

6.5.4 Two small markers (for example, cones) to mark the turnaround points,

6.5.5 Tape (bright colored),

6.5.6 A chair that can be easily moved along the walking course, and

6.5.7 Test report (see Section 9).

10MWT

6.6 The walking course shall be 10 m (33 ft) in length with at least 2 m additional space beyond the end for deceleration. A starting line should be marked on the floor using brightly colored tape. Tape marks should be placed at 1 m and 9 m from the START line.

6.7 Required Apparatus:

6.7.1 Stopwatch,

6.7.2 12 m long or greater straight, unimpeded corridor or path,





a



b



c



d



e



f

NOTE 1—Examples include: (a) medical rehabilitation (courtesy Gogo), (b) military material handling (courtesy Mawashi), (c) military soldiering (courtesy Mawashi), (d) recreational hiking through snow and (e) walking on pavement as part of daily work duties (courtesy Humotech), and (f) industrial worker standing up from a chair prior to walking (courtesy SuitX).

FIG. 1 Examples of Exoskeleton Users Walking in Various Sectors

- 6.7.3 Tape (bright colored), and
- 6.7.4 Test report (see Section 9).

TUG

6.8 The course shall be 3 m (10 ft) in length with 2 m additional space beyond for turnaround. A chair with armrests is placed at one end of the course. An END line should be marked on the floor using brightly colored tape at 3 m from the front of the chair.

6.9 Required Apparatus:

- 6.9.1 5 m long or greater straight, unimpeded corridor or path,

- 6.9.2 Chair with armrests,
- 6.9.3 Stopwatch,
- 6.9.4 Tape (bright colored), and
- 6.9.5 Test report (see Section 9).

7. Hazards

7.1 Hazards for gait tests when using exoskeletons can be as follows: slips, trips, falls, fatigue, and collisions dependent upon the exoskeleton, the test environment, and the apparatus (for example: chairs, surrounding walls). Refer to the References section (4 and 5) in order to characterize biomechanical stressors. Note that although these references are typical

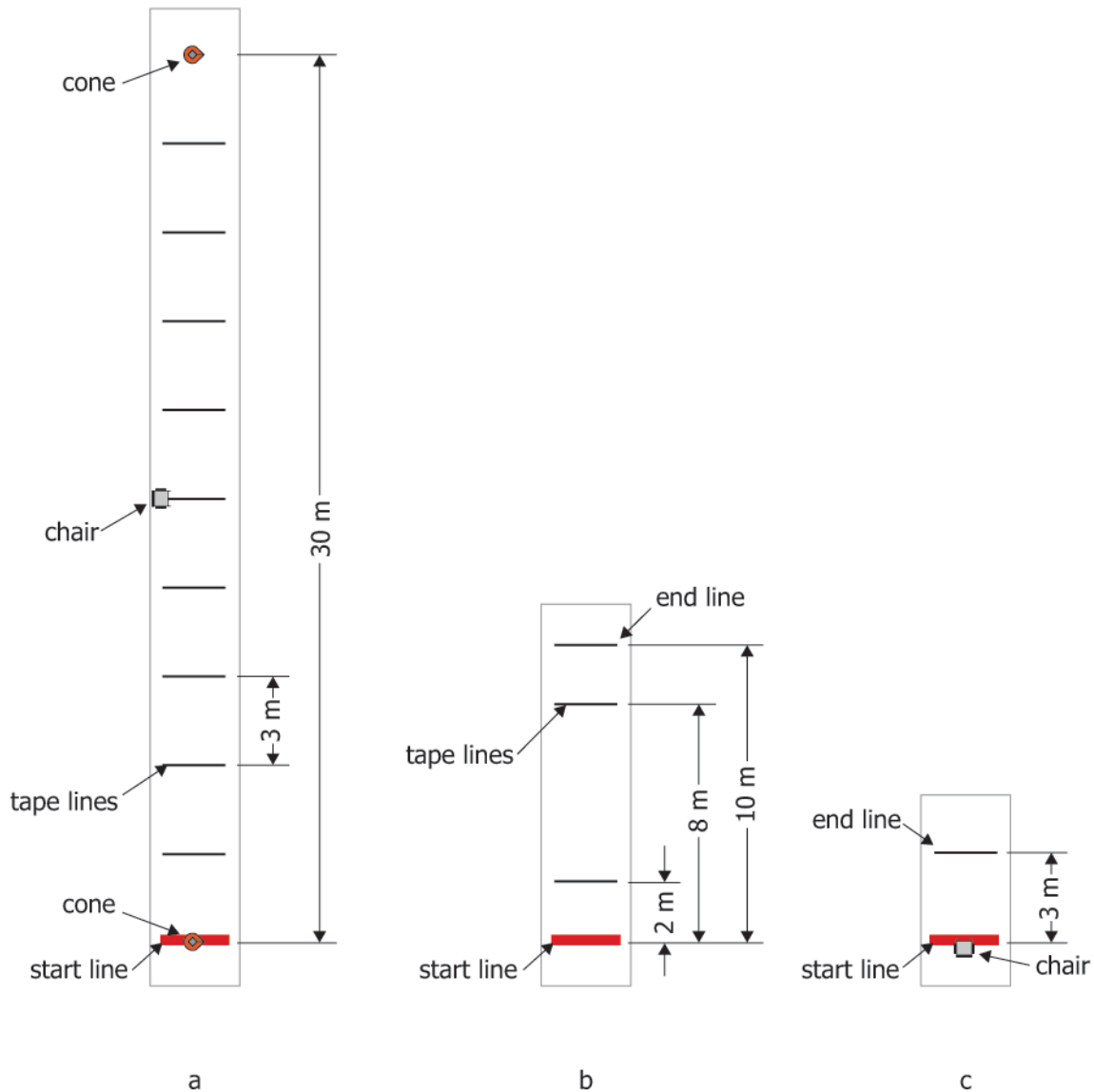


FIG. 2 Gait Test Course Layouts for (a) 6MWT, (b) 10MWT, and (c) TUG test

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 Robots and robotic devices — Safety requirements for personal care robots;

7.2.2 ASTM Guide for Safety Considerations in Designing and Selecting Exoskeletons for Industrial, Medical and Military Applications;⁵

7.2.3 ASTM Guide for System Usefulness and Usability;⁵

7.2.4 ASTM Guide for Hazards for Consideration when Designing Exoskeletons;⁵

7.2.5 ASTM Guide for General Guidelines to Risk Management of Exoskeletons;⁵ and

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

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

⁵ New standard under development.