



Designation: F3578 – 22

Standard Test Method for Evaluating Exoskeleton Fall Risk due to Stumbling¹

This standard is issued under the fixed designation F3578; 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 is to evaluate the extent to which an exoskeleton (see Section 3) improves, inhibits, or maintains (that is, does not affect) a user's ability to recover from a stumble perturbation.

1.1.2 Exoskeletons are designed to assist specific tasks and initially tested in controlled lab or controlled field settings. However, in the real world exoskeletons encounter less structured environments and situations (for example, hospital rooms, factory floors, construction sites). Even without exoskeletons people will stumble (that is, trip) or scuff their foot. It would be helpful to understand how wearing an exoskeleton affects a person's ability to recover from a stumble perturbation. Is one's ability to recover hampered, enhanced, or unaltered when using an exoskeleton? This test method specifies test setup, procedure, and recording to standardize testing exoskeleton user stumble recovery.

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

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 standard-*

ization 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

3. Terminology

3.1 General terminology for ASTM Committee F48 standards is listed in Terminology F3323. Terminology specific to this standard are 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 *artifact, n*—a representative of real structure(s), object(s), or test component(s) and used for a test.

3.2.3 *perturbation, n*—external disruption to body movement; in this standard, a perturbation specifically refers to a disruption to the lower limb trajectory during swing phase of gait due to an obstacle.

3.2.4 *scuff, n*—perturbation to the bottom of the foot during swing phase.

3.2.5 *stumble, n*—the act of tripping or losing balance as a result of a perturbation to the front of the foot/toe during swing phase.

4. Summary of Test Method

4.1 The task for this test method, exoskeleton user stumble recovery, is defined as the exoskeleton user stumbling during

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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.

walking. This task is used to assess the extent to which an exoskeleton improves, inhibits, or maintains a person's ability to recover from a stumble. The task involves an exoskeleton user walking on a treadmill and experiencing a perturbation.

4.1.1 This test method can also be used to examine the response of the exoskeleton user to scuffs and other perturbation types, see [6.5.3](#).

4.2 The number of perturbations and conditions for each perturbation will be defined by the test requester prior to the test. The recommended apparatuses are described in [Section 5](#). The test requester also selects the participants for the test, which should be representative of the expected user population of the exoskeleton to be tested.

4.3 The exoskeleton's capability is defined as the fall or recovery outcome of the task, as determined by the weight-bearing assistance provided by a force-instrumented overhead safety harness (see [Section 6](#)) and optionally the maximum trunk flexion after the perturbation as measured, for instance, by optical motion capture, a goniometer, or inertial measurement unit (IMU). These outcome metrics are evaluated by comparing the baseline case (that is, no exoskeleton) to the exoskeleton case to determine whether the exoskeleton improves, impedes, or maintains the exoskeleton user's performance (that is, fewer falls or less trunk flexion, or both, relative to baseline are improvements; more falls or more trunk flexion, or both, are impediments). The test requester can specify the number of perturbations, and as such, total falls out of total tests shall be recorded and used as the exoskeleton's fall risk, and can be compared to the user's fall risk in the baseline case, see [8.4](#).

4.3.1 All users are required to wear a harness to catch them after a fall to mitigate risk of injury. It is suggested that if the load cell measures >50 % bodyweight after a perturbation trial, even those including an apparent recovery, that trial should be recorded as a fall.

4.4 The exoskeleton user may undergo a familiarization period and practice walking on the treadmill with the sensory occlusion equipment (that is, dribble goggles to block the inferior visual field and wireless earbuds playing white noise along with noise cancelling headphones to block hearing, see [Section 6](#)) and harness prior to the test, see [9.8.8](#).

4.4.1 Practice is encouraged due to the potentially disorienting initial effects of the sensory occlusion equipment or discomfort associated with wearing a harness, or both. It is suggested that the exoskeleton user practice walking with and without the exoskeleton until they indicate they are comfortable walking continuously for 120 s or more. The practice time and protocol, as well as any prior experience by the user wearing the exoskeleton, should be described in the test report.

4.5 Additionally, acclimation to the perturbation protocol is recommended by allowing the user to experience at least one perturbation for both exoskeleton and baseline (no exoskeleton) cases to avoid inclusion of a potentially inconsistent first-time response in the data, see [9.8.8](#). The acclimation time and protocol, as well as any prior experience by the user with the test apparatus, should be included in the test report.

4.6 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 concerns or physical discomfort. The user shall have the authority to request that the test be stopped at any point during the trial. However, it is the test supervisor's authority to judge the completeness of the repetition. If the testing is stopped before all specified trials are completed, the test is marked as incomplete.

4.7 The test requester has the authority to select the parameters that may affect the user for the task. The test requester 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:

4.7.1 Leg swing percentage of perturbation;

4.7.2 Side experiencing perturbation (that is, right limb vs. left limb);

4.7.3 Obstacle weight and dimensions:

4.7.3.1 Changing the dimensions of the obstacle can allow the test to include scuffs and other perturbations, see [6.5.3](#).

4.7.4 Walking speed;

4.7.5 Environmental conditions including, for example, ground surfaces that are level or sloped or uneven/undulating; hard or soft; temperatures levels that are normal or extreme ([Practice F3427](#)); and

4.7.6 While carrying a load(s) ([Practice F3443](#)).

5. Significance and Use

5.1 There is strong evidence that exoskeletons can physically augment and assist users. They are typically designed and optimized with specific tasks in mind and initially tested in controlled lab or field settings. However, in the real world exoskeletons encounter less structured environments and situations (for example, hospital rooms, factory floors, construction sites, or even personal homes). In order to accelerate the adoption of exoskeletons in society, understanding their safety in the presence of perturbations is helpful. The testing results of the exoskeleton shall describe the extent to which the exoskeleton improves, inhibits, or maintains a user's ability to recover from stumbles, thus providing exoskeleton wearers and prescribers (for example, patients, clinicians, industry leaders, factory workers) with additional information about device performance and expectations.

5.2 The standard test apparatus and setup (see [Section 6](#)) is specified to be easily fabricated and implemented in gait or motion analysis laboratories. Variants of the apparatus, control algorithm, and test setup are acceptable to allow implementation in various lab settings with ranging experimental capabilities. 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 performance of their exoskeleton(s) for tasks.