



Designation: F3612 – 24

Standard Practice for Lower Extremity Exoskeleton Locomotion Transitions¹

This standard is issued under the fixed designation F3612; 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 When an exoskeleton operator moves within their environment, they will encounter transitions (for example, level ground to ramps or stairs). These environments and transitions will naturally require different biomechanical patterns (1).² As such, it is important to evaluate an exoskeleton's ability to perform transitions during human-exoskeleton operation.

1.2 This practice provides tools for assessing an exoskeleton's ability to transition between objects or structures in the environment. Apparatus and desired performance criteria are identified to support transition assessment and direct and perceived measures of performance are provided.

1.3 Purpose:

1.3.1 This practice provides a set of instructions for the evaluation of an exoskeleton's (see Terminology F3323) ability to transition (see definitions in Section 3) between representative apparatus in the environment.

1.3.2 This practice can be used independently or can be applied for use with test methods (for example, gait transitioning to ramps). A test report is therefore included and provides an independent evaluation of transition.

1.3.3 This practice contributes to the evaluation of exoskeletons within the domains of industry, military, medical, emergency response, and recreation. Exoskeletons possess a certain set of allowable user movements that may vary by task and goals. Environments in these typical sectors often pose constraints to exoskeleton user movement to various degrees. Being able to transition as intended by the user or test requestor while using an exoskeleton is essential for exoskeleton deployment in a use-case relevant environment.

1.3.4 This practice provides four suggested course configurations that recreate transition scenarios based on anticipated environments, apparatus, and applicable transitions. This practice includes metrics and build criteria for these courses.

Alternate course configurations may be selected and should be documented following the guidelines provided.

1.4 Exoskeletons should be able to smoothly transition between different apparatus without undesired or detrimental reactions. Intended exoskeleton purpose by the manufacturer will determine the relevant apparatus configurations and test methods to be used.

1.5 *Performing Location*—This practice should be performed in a testing laboratory or the field where the specified apparatus and environmental conditions are implemented.

1.6 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 *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.*

1.8 *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:³

E2801 Test Method for Evaluating Emergency Response Robot Capabilities: Mobility: Confined Area Obstacles: Gaps

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

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

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

- F3527 Guide for Assessing Risks Related to Implementation of Exoskeletons in Task-Specific Environments
 F3528 Test Method for Exoskeleton Use: Gait
 F3540 Guide for Hazards for Consideration when Designing Exoskeletons
 F3576 Practice for Recording the Exoskeleton Test Configuration
 F3580 Test Method for Exoskeleton Use: Stairs
 F3582 Test Method for Exoskeleton Use: Gaps
 F3584 Test Method for Exoskeleton Use: Obstacle Avoidance: Walking
 F3613 Practice for Recording the Exoskeleton Fit to the User
 F3614 Practice for Recording the Exoskeleton User Information
 2.2 *Federal Standards*:⁴
 CFR 1910.25 Walking-Working Surfaces: Subpart D - Stairways
 28 CFR Part 36 (1991) Americans with Disabilities Act
 2.3 *ISO Standards*:⁵
 ISO/IEC GUIDE 51 Safety Aspects — Guidelines for their Inclusion in Standards
 EN 13921 Personal Protective Equipment — Ergonomic Principles
 ISO 13482 Robots and Robotic Devices — Safety Requirements for Personal Care Robots
 ISO 14971 Medical Devices — Application of Risk Management to Medical Devices
 ISO 31000 Risk Management — Guideline
 2.4 *Other Documents*:⁶
 2018 International Building Code (IBC)

3. Terminology

3.1 Definitions:

3.1.1 Many terms used within this practice are defined as in Terminology F3323, as listed here.

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

3.1.3 *test supervisor, n*—person responsible for setting up the apparatus, instrumentation, directing, and reporting results of the test according to the test requestor.

3.1.4 *test requestor, n*—person or organization selecting the test(s) and defining the conditions under which they are performed.

3.1.5 *user, n*—the individual that wears an exoskeleton.

3.2 Definitions of Terms Specific to This Standard:⁷

3.2.1 *course configuration, n*—an arrangement of predetermined apparatus within a testing area.

⁴ Available from U.S. Government Publishing Office (GPO), 732 N. Capitol St., NW, Washington, DC 20401, <http://www.gpo.gov>.

⁵ Available from International Organization for Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <https://www.iso.org>.

⁶ Available from International Code Council (ICC), 500 New Jersey Ave., NW, 6th Floor, Washington, DC 20001, <http://www.iccsafe.org>.

⁷ These terms are not currently defined within Terminology F3323.

3.2.2 *cross-slope, n*—angled surface that is perpendicular to the travel direction and tilted with respect to a level surface (see Fig. 1).

3.2.3 *exoskeleton status, adj*—exoskeleton status when worn by the user can be in two states: “Powered/Engaged” describes the exoskeleton status of a trial where the exoskeleton is worn and turned on; “Unpowered/Disengaged” describes the exoskeleton status of a trial where the exoskeleton is worn but turned off.

3.2.4 *flat-floor terrain element, n*—flat surface apparatus that can be incorporated within a course configuration, may be of varying elevation. **E2801 – 11**

3.2.5 *ramp, n*—a sloping surface or plane, such as: a sloping floor, walk, or roadway leading from one elevation level to another.

3.2.6 *stairs, n*—a set of steps leading from one floor of a building to a landing or another floor. **F3580**

3.2.7 *transition, n/v*—to move from one apparatus to another.

4. Summary of Practice

4.1 This practice is defined as a user wearing an exoskeleton and moving through a course that includes stairs, ramps, or landings, or combinations thereof, of different inclinations/heights, with the opportunity for a cross-slope or additional obstacles. This practice can be (1) independently used as described, or (2) used with test methods, for example when transitioning between gait and ramps or stairs. Each apparatus, that forms the courses provided in this practice, is modular and can be arranged into four different suggested configurations that support different types of transitions. When each apparatus is from a test method, the test course should be similarly

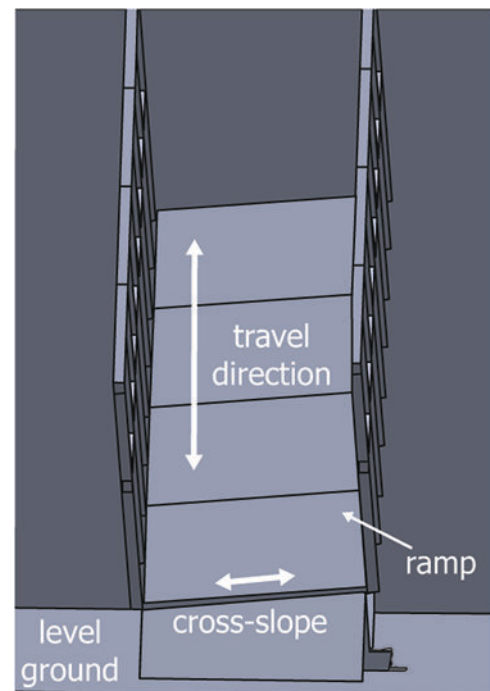


FIG. 1 Cross-slope

described as, for example, level ground transitioning to a ramp with an associated drawing or photo of the apparatus provided. The test requestor should choose from the apparatus configurations based on the type of testing needed for their use case, as well as specific testing instructions, including the number of repetitions required. It is important that the test requestor obtains baseline data when users are not wearing the exoskeleton to enable comparison of user's performance between possible exoskeleton states.

4.2 This practice includes information or reports, or both, for three example evaluation methods: direct measures, user perception, and test supervisor observation.

4.2.1 *Direct measures* are performance outcomes that are measured by using a device (for example, stopwatch, sensor). Recommended direct measures are provided in [Appendix X1](#).

4.2.2 *User perception* is a set of questions designed to capture relevant characteristics of performance as perceived by the user after moving through the course. An example set of questions is provided in [Appendix X2](#).

4.2.3 *The test supervisor's observation* is a test report designed for the test supervisor to assess the user's performance with the exoskeleton while moving through the course. An example test report is provided in [Section 12](#).

4.3 The test report (see [Section 12](#)) contains three sections:

4.3.1 *Exoskeleton and Devices*—Practice [F3576](#) should be used by the test supervisor and user prior to the start of testing. Data regarding testing information, exoskeleton information, and devices used for testing should be recorded in this section of the test form. Recording exoskeleton information is imperative to understanding results, potential comparisons, and overall evaluation. These data are relevant because testing is dependent on course configuration and exoskeleton makes, models, and configuration.

4.3.2 *User Demographics*—Practice [F3614](#) should be filled out by the user prior to the start of testing. The user should provide the requested demographic information in which the data supports documenting diversity, safety, and the relationship between the user's experience and testing results.

4.3.3 *User Perception of Performance*—This section, shown in [Appendix X1](#), contains questions that the user should answer. The user should familiarize themselves with the terms listed at the beginning of this section before answering all questions.

4.4 The exoskeleton's capability is defined as the exoskeleton's ability to complete the course configuration where the user is capable of performing all tasks in the course as per the instructions given by the test requestor and test supervisor. Further, the test requestor can specify the statistical reliability and confidence levels of such a capability and thus, dictate the number of successful course repetitions that are required.

4.5 The user is allowed to practice before the test begins. The user shall be allowed to withdraw from the test before it is started or during the test. The test supervisor has the authority to evaluate the completeness of a repetition and overall user's performance during the test. The test supervisor may ask the user to repeat a repetition if the repetition is deemed to be incomplete or invalid. An additional repetition should only

occur if the instructions are not followed, such as a deviation from the procedure. Additional repetitions should not be added to achieve improved performance. The test supervisor may terminate the user's participation in the test if the user is deemed ineligible or incapable of performing the test (for example, high heart rate). If problems or other issues arise before or during the test, the test supervisor has the authority to cancel or reschedule the test.

NOTE 1—Practice could help establish the applicability of the exoskeleton for the given test. It allows the user 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 combinations thereof.

4.6 The test requestor has the authority to select the test apparatus, course configuration, and performance metrics and devices that will be used for testing, to specify test prompts, to determine the corresponding statistical reliability and confidence levels of the results for the test, and to establish the participation rules, including the testing schedules and environmental conditions (see Practice [F3427](#)). The test supervisor may establish additional rules other than rules established by the test requestor. There are recommended devices, apparatus, and course configurations listed in [Section 6](#) of this practice. The selections made by a test requestor and any variations to this practice should be documented in the test forms.

4.7 Once the test begins, verbal and nonverbal communication between the user and the test supervisor regarding user performance is discouraged, unless related to testing procedure and safety. The user has the responsibility to determine if they have the capability (for example, appropriate heart rate, physical stamina) to complete a repetition and notify the test supervisor accordingly. It is the test supervisor's authority to evaluate the completeness of the repetition and whether or not to continue the test. The test supervisor should be available to answer any questions from the user while the user is filling out the test form.

5. Significance and Use

5.1 Exoskeletons may be used in several domains, including for example, industrial, military, first-response, medical, and recreational, to provide potential benefits in supporting user capability, as well as the potential to prevent injury. Exoskeletons may be required to traverse objects, such as stairs and ramps, in unstructured, complex environments.

5.2 All course configurations and recommended apparatus should be in compliance with the following safety standards: Americans with Disabilities Act (ADA), Architectural Graphic Standards ([2](#)), International Building Code, and Occupational Safety and Health Administration (OSHA) Regulations. However, not all stairs, ramps, and cross-slopes will meet these criteria as they arise from unstructured natural elevation changes (for example, hills, mountains), or are in buildings that do not meet current standards. If the operational environment of interest requires usage in these environments, care must be taken to ensure test safety. For all artifacts selected, dimensions should be documented, as noted on the [test form](#).

12). Tables provided in 5.2.1 – 5.2.3 are summarized from the ADA and OSHA references showing maximum and minimum values.

5.2.1 A summary of standard stair measurements is provided in Table 1.

5.2.2 A summary of standard ramp measurements is provided in Table 2.

5.2.3 A summary of standard cross-slope measurement is provided in Table 3.

5.3 The apparatus is recommended to be modular such that they can be arranged into different course configurations to facilitate exoskeleton assessment in multiple scenarios based on test requestor and user requirements. The standard course configurations include four configurations (see Section 6) designed for a range of needs, including traversing common situations and density of transitions.

6. Apparatus and Course Configuration

6.1 The course configuration and apparatus described in this practice should be used according to the recommendations provided in this practice.

6.2 *Optional Test Equipment and Devices:*

6.2.1 *Stopwatch,*

6.2.2 *Motion Capture System* (for example, optical tracking system),

6.2.3 *Inertial Measurement Units (IMUs),* and

6.2.4 Other devices not listed in this practice are allowed to be used if necessary and should be listed on the test report.

6.3 The actual apparatus (for example, a building entrance with ramps), combined test methods (for example, gait transitioning to ramp, etc.), or the apparatus described in 6.4 can be used for this practice and should be shown on the test report (see Section 12).

6.4 *Apparatus*—The following apparatus is described and will be used for the remainder of this practice as an example for course configurations (see 6.8), test preparation, and procedure. One apparatus configuration is introduced in Fig. 2 and is repeated in Fig. 3 with abbreviated descriptors used to detail various apparatus configurations.

6.4.1 *Stairs 1 (S-1)*—A set of stairs with six steps where each step has 0.1 m riser height, 0.5 m tread depth, and 1.22 m tread width. Overall footprint space of S-1 measures 2.7 m long, 1.2 m wide, and 0.6 m high. These specifications are based on the minimum riser height and maximum tread depth in compliance with safety standards. S-1 is included in suggested Configuration A, Configuration B1, and Configuration B2.

6.4.2 *Stairs 2 (S-2)*—A set of stairs with four steps where each step has 0.2 m riser height, 0.3 m tread depth, and 1.22 m tread width. Overall footprint space of S-2 measures 1.2 m long, 1.2 m wide, and 0.7 m high. These specifications are

based on the maximum riser height and minimum tread depth in compliance with safety standards. S-2 is included in all suggested configurations.

6.4.3 *Ramp 1 (R-1)*—A ramp with 1:8 gradient. Overall footprint space of R-1 measures 7.3 m long, 1.2 m wide, and 0.6 m high. These specifications are defined to test the exoskeleton on a gentler slope. R-1 is included in suggested Configuration A, Configuration B1, and Configuration B2.

6.4.4 *Ramp 2 (R-2)*—A ramp with 1:12 gradient. Overall footprint space of R-2 measures 5.7 m long, 1.2 m wide, and 0.7 m high. These specifications are based on the maximum slope allowed by safety standards. R-2 is included in all suggested configurations.

6.4.5 *Landing 0 (L-0)*—A flat-floor terrain element on ground level and measures 1.2 m by 1.2 m that is located on every bottom step of stairs and ramps. L-0 connects the ground level with every apparatus of the course and between two level ground apparatus. Ground spaces for L-0 are included in all suggested configurations to comply with safety standards in 5.2.

6.4.6 *Landing 1 (L-1)*—An elevated flat-floor terrain element that is 0.6 m high and measures 1.2 m by 1.2 m. L-1 is able to connect L-1 and R-1, and with L-2 to connect with S-2 and R-2. L-1 is included in suggested Configuration A, Configuration B1, and Configuration B2 to comply with safety standards in 5.2.

6.4.7 *Landing 2 (L-2)*—An elevated flat-floor terrain element that is 0.7 m high and measures 1.2 m by 1.2 m. There are three L-2s in total, and L-2s are able to connect S-1, S-2, R-2, and L-1 with R-1. To comply with safety standards in 5.2, three L-2s are required for Configuration A, two L-2s for Configuration B2 and Configuration C, and one L-2 for Configuration B1.

6.4.8 *Cross Slope (C-0)*—A 1:10 slope that is 5.0 m long, 1.2 m wide, and 0.1 m high. The length is based on the distance of average step lengths for an adult male (0.8 m, (3)). The length of C-0 is 5.0 m to enable approximately six steps. C-0 is included in suggested Configuration A.

6.4.9 *Obstacle Strip (O-0)*—An area on ground level that measures 5.0 m long and 1.2 m wide that contains three height-adjustable obstacle bars. Similar to C-0, the length is based on the distance of average adult male step lengths to enable approximately six steps. The recommended size of the height-adjustable obstacle bars should be approximately the width of O-0 (1.2 m) and have a range of heights that enable the user to maneuver over and under the bars. O-0 is included in suggested Configuration A.

6.5 This practice recommends four distinct course configurations shown in: (A) Figs. 3-5; (B1) Figs. 6-8; (B2) Figs. 9-11; and (C) Figs. 12-14. Isometric and top views of each configuration and an example path for each configuration are provided in 6.7. Paths are provided only as an example as the test requestor can suggest an alternative path(s). The path should be provided on the test report. On each of the isometric views, labels are provided on each apparatus for identification. On each of the top views, measurements of each apparatus are provided for scale.

TABLE 1 Summary of Standard Measurements for Stairs

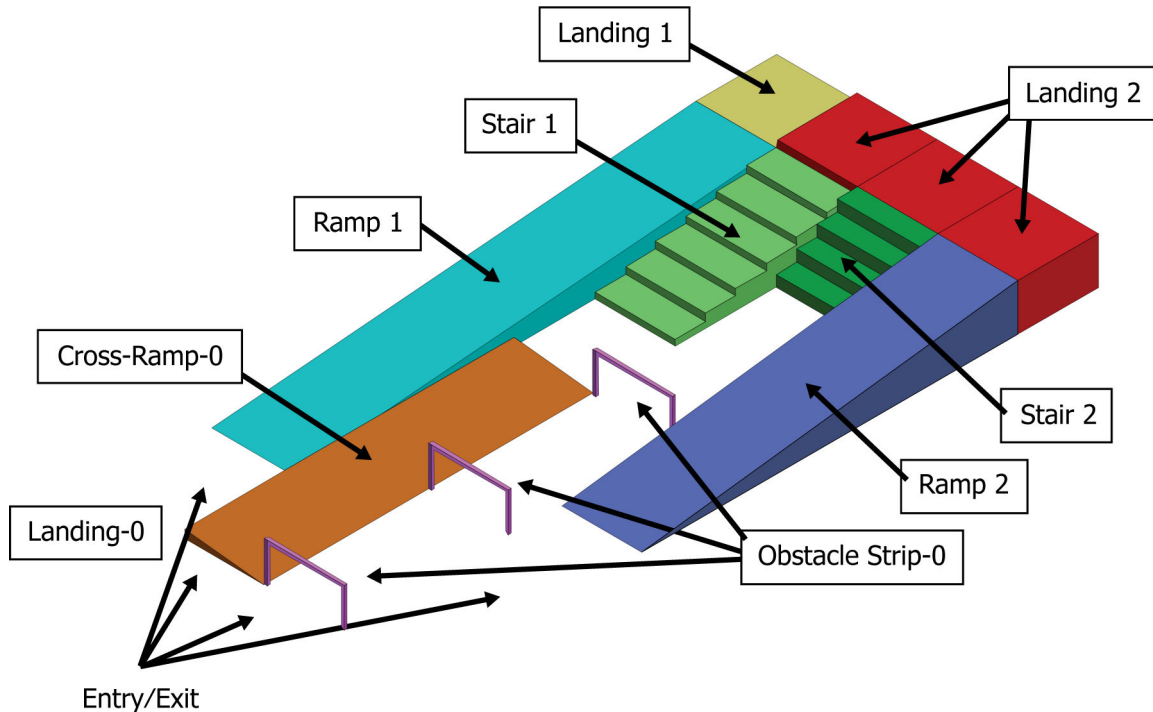
Stairs	Riser Height (m)	Tread Depth (m)
Maximum	0.18 to 0.24	0.46
Minimum	0.10	0.24 to 0.30

TABLE 2 Summary of Standard Measurements for Ramps

Ramp	Slope (Rise : Run)	Percent Slope (%)	Angle (deg)	Rise (m)
Maximum	1:12	8.3	4.76	0.76
Minimum	N/A	N/A	N/A	N/A

TABLE 3 Summary of Standard Measurements for Cross-slopes

Cross Slope	Slope (Rise : Run)	Percent Slope (%)	Angle (deg)	Rise (m)
Maximum	1:48	2.1	1.19	N/A
Minimum	N/A	N/A	N/A	N/A



Landing-0 is the flat floor on which the apparatus is set.

FIG. 2 Example Apparatus

6.6 The four distinct course configurations are recommended based on several factors. Each course configuration is designed to meet standard sizing requirements for stairs and ramps (see 5.2). The recommended course configurations allow the test requestor to select the best-suited course for their needs and space availability. The largest configuration includes all apparatus and all possible transitions between apparatus. The simplest course configuration is to simulate real-life examples, for example, a building entrance. The footprint size varying from small to large in course configurations allows for one to be chosen and fitted in a laboratory or outdoor setting. Note: The actual course configuration (for example, a building entrance) can be used as the test course configuration. Each of the apparatuses are modular to offer flexibility of course configuration layouts to be fitted in both indoor and outdoor test sites.

6.7 If different apparatus dimensions are selected to align with the operational use case beyond the recommended

apparatus, it is important to be aware that there are dependencies in dimensions between apparatuses based on the needs to have starting/ending heights that enable coupling of the apparatuses together to form a course.

6.8 The recommended course configurations are as follows:

6.8.1 *Configuration A*—A configuration designed to include all apparatuses and all possible transitions between apparatuses. L-1 and three L-2s are adjacent to each other and form a straight path to simulate level-ground walking. The highest point of R-1 is connected to L-1, and R-1 is perpendicular to the direction of travel of the straight path formed by the landings. The highest step of S-1 is connected to L-2 and S-1 is adjacent and parallel to R-1. The highest step of S-2 is connected to L-2, and S-2 is adjacent and parallel to S-1. The highest point of R-2 is connected to L-2, and R-2 is adjacent and parallel to S-2. The lowest point of all stairs and ramps are connected to L-0. C-0 is placed adjacent to R-1 and parallel to S-1. The highest side of C-0 is adjacent to S-1.

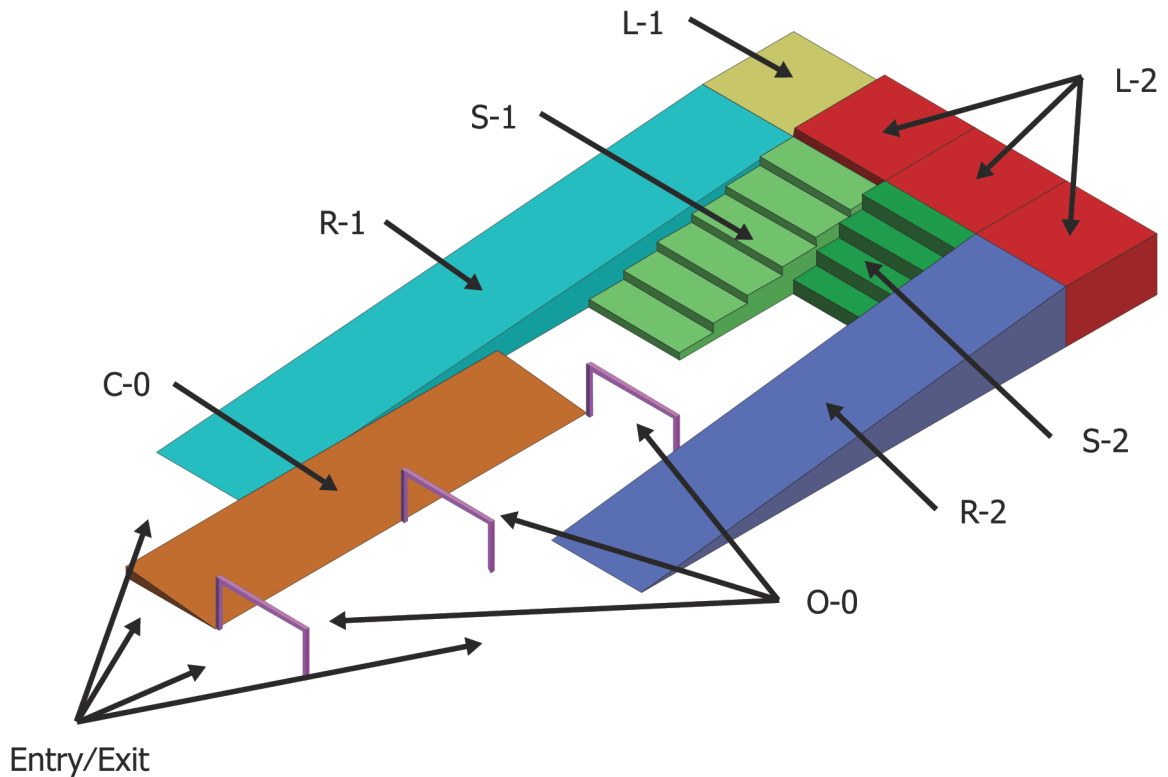


FIG. 3 Configuration A (Isometric View)

and the lowest step of S-1 share the same L-0, and the other end of C-0 is connected to L-0. O-0 is placed adjacent and parallel to C-0, and both ends are connected with L-0s. Four entry and exit points are possible in this configuration at R-1, C-0, O-0, and R-2. An isometric and a top view of Configuration A are provided in Fig. 3 and Fig. 4.

6.8.1.1 An example path through Configuration A is provided in Fig. 5.

6.8.2 *Configuration B*—A configuration (B1) designed as a combination between a configuration that includes all apparatuses and (B2) all transitions possible, and another configuration that is designed after a building frontage with minimal amount of transitions.

6.8.2.1 *Configuration B1*—A type of Configuration B that is composed of S-1, S-2, R-1, R-2, four L-0s, L-1, and L-2. The lowest step of S-1 is connected to L-0, and the highest step of S-1 is connected to L-1. The highest point of R-1 is connected to the same L-1 that the highest step of S-1 is connected to, and the lowest point of R-1 is connected to L-0. The lowest step of S-2 is connected to L-0, and the highest step of S-2 is connected to L-2. The highest point of R-2 is connected to the same L-2 that the highest step of S-1 is connected to, and the lowest point of R-2 is connected to L-0. The set of S-1, L-1, and R-1 is parallel to the set of S-2, L-2, and R-2. Four entry and exit points are possible in this configuration at S-1, S-2, R-1, and R-2. An isometric and a top view of Configuration B1 is provided in Fig. 6, Fig. 7, and Fig. 8. An example path through Configuration B1 is provided in Fig. 8.

6.8.2.2 *Configuration B2*—A type of configuration B that is composed of S-1, S-2, R-1, R-2, four L-0s, L-1, and two L-2s. The lowest step of S-1 is connected to L-0, and the highest step

of S-1 is connected to L-1. L-1 is connected to L-2, and L-2 is connected to another L-2. The top step of S-2 is connected to the L-2 at the edge, and the lowest step of S-2 is connected to L-0. S-1, L-1, two L-2s, and S-2 are connected together and form a straight path. The lowest point of both R-1 and R-2 is connected to L-0. The highest point of R-1 is connected to L-1, and the highest point of R-2 is connected to the L-2 adjacent to L-1. R-1 and R-2 are placed adjacent and parallel to each other. The two ramps are connected in a manner that the direction of travel of the stairs and ramps are perpendicular to each other. An isometric and a top view of Configuration B2 is in Fig. 9, Fig. 10, and Fig. 11. An example path through Configuration B2 is provided in Fig. 11.

6.8.3 *Configuration C*—A configuration designed after a building frontage that is composed of S-2, R-2, two L-2s, and two L-0s. Most building frontages incorporate a combination of stairs and ramps. The lowest step of S-2 is connected to L-0, and the highest step of S-2 is connected to L-2. The lowest point of R-2 is connected to L-0, and the highest point of R-2 is connected to L-2. S-2 and R-2 are connected in a perpendicular manner to each other in terms of the direction of travel. An isometric view and a top view of Configuration C is provided in Fig. 12, Fig. 13, and Fig. 14.

6.8.3.1 An example path through Configuration C is provided in Fig. 14.

7. Hazards

7.1 Hazards while walking on the course may include falling, tripping, fatigue, and collisions, depending upon the exoskeleton, the test site, and the apparatus. Emergency egress from the test site should also be considered.

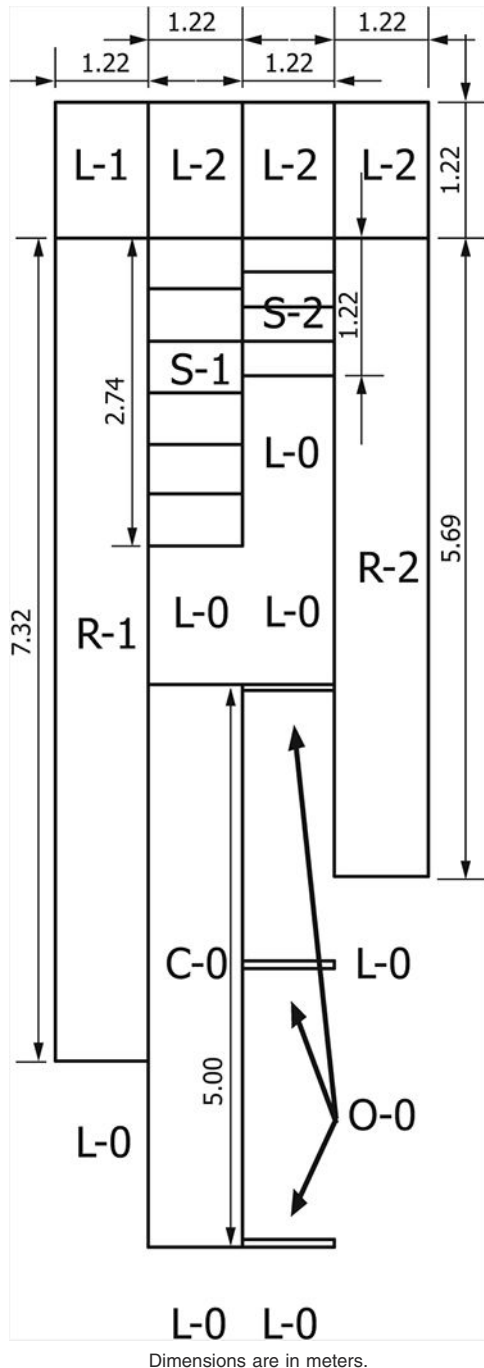


FIG. 4 Configuration A (Top View)

emergency. Additional risks and mitigation procedures may be needed for specific exoskeleton designs.

7.2 While not shown in the diagrams, handrails should be installed on each apparatus during testing, or a safety harness used, to support safety. Appropriate safety organization guidelines (for example, OSHA) should be followed where appropriate. All apparatus used must be secured properly by using appropriate tools as directed by the apparatus manufacturer.

7.3 Applicable safety standards that provide risks and hazard mitigation procedures for exoskeleton use that are devel-

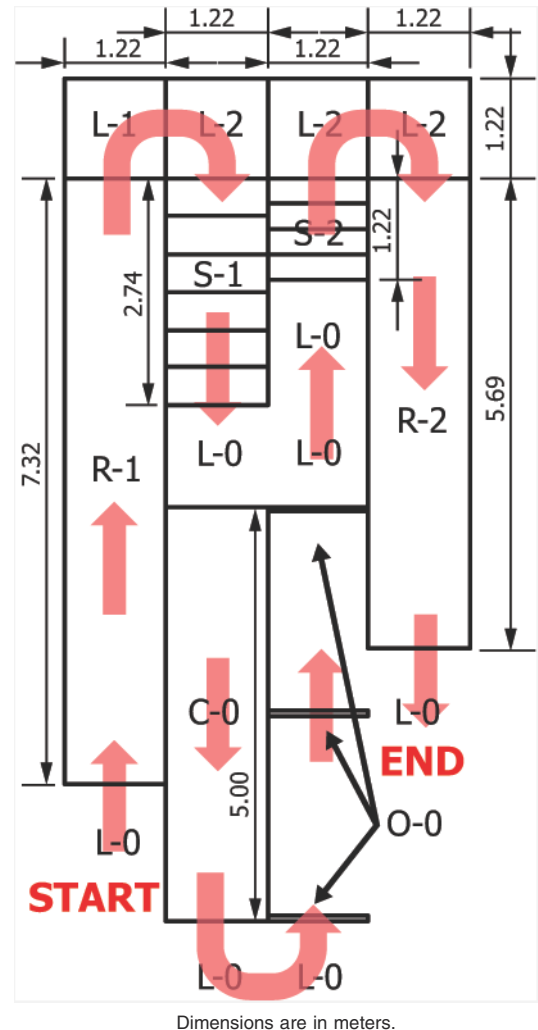


FIG. 5 An Example Path through Configuration A

oped or being developed: ISO 13482; Guide F3527 – 17; Guide F3540; Test Method for Measuring Exoskeleton Cognitive Fit, Perceived Safety, and Acceptance; Risk Assessment and Management for Exoskeleton Design and Manufacturing; Risk Assessment and Management for Exoskeleton Implementation; and Risk Assessment and Management of Exoskeletons Throughout Production and Implementation.⁸

8. Test Preparation

8.1 The exoskeleton(s) being tested should be documented on the test report (see Section 12). Also, see Ref (4) for test evaluation. This includes version/iteration details as well. A full description of the exoskeleton and it's fit to the user should be reported in Practices F3576 and F3613, respectively. If the exoskeleton(s) have parts that can be rearranged, include this arrangement as well. Any variation in exoskeleton configuration should cause the resulting exoskeleton variant to be retested across all repetitions to provide a consistent and comprehensive representation of performance.

⁸ The titles listed here are proposed titles for standards that are under development.

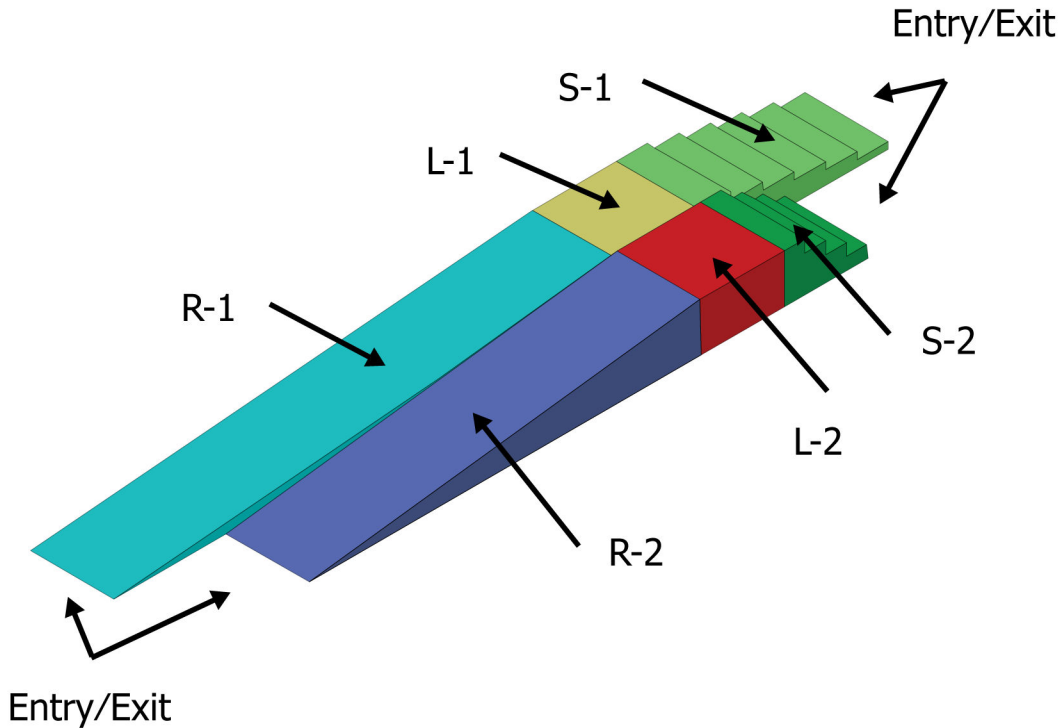


FIG. 6 Configuration B1 (Isometric View)

8.2 Once an exoskeleton user begins a test as instructed by the test supervisor, the exoskeleton should be used to perform the task for the specified number of repetitions to completion without changing the exoskeleton, apparatus, course configuration, and path.

8.3 A battery may be changed or charged between repetitions provided that other exoskeleton configurations, apparatus, and course configuration remain unaltered, unless prohibited by the test requestor. If at any point the exoskeleton has a failure which requires maintenance, a battery swap, physical intervention, or repairs, the test should be restarted or canceled if the failure poses safety concerns. These failures should be noted within the appropriate test form sections.

8.4 The recommended direct measures for this practice are listed in [Appendix X1](#). All direct measures recorded during the test should be listed on the test form.

9. Procedure

9.1 The test requestor should first specify the environmental conditions where the exoskeleton will be tested (for example, [Practice F3427](#)) and the exoskeleton test configuration (for example, [Practice F3576](#)) used for the exoskeleton assessment. The course configuration and apparatus used for exoskeleton assessment should be documented in the test report.

9.2 All apparatuses are recommended to be used and arranged as directed by the course configuration recommendations provided in this practice. The selected course configuration should be documented on the test report.

9.3 Details about the exoskeleton's make, model, and specifications being assessed should be documented by the test supervisor on the test report provided in this practice prior to the start of testing.

9.4 The user should provide the necessary demographic information (for example, [Practice F3614](#)).

9.5 The user should complete at least one practice repetition of the course configuration each without wearing and while wearing the exoskeleton until they are comfortable with walking through the course configuration. Then, the user should be familiarized with the questions in the user perception of performance section ([Appendix X2](#)). Subsequently, the user is fitted with the exoskeleton and report the fit accordingly (for example, [Practice F3613](#)) and any sensors (for example, for motion capture, IMU) if they are being used (for example, [Practice F3576](#)). The test requestor then specifies test prompts according to their purpose of testing for the user to follow.

9.6 The user should perform the testing as instructed by the test requestor's prompts.

9.7 An example test method for this practice is as follows (note, "shall" is used in the example as would be expected of a test method):

9.7.1 Ensure that the course is set up and all apparatuses are secured. The course shall be clean from debris, liquid, moisture, and other foreign objects that do not belong on the course.

9.7.2 Ensure that all measuring devices are set up and ready to be operated and secured, if necessary.