Designation: F3518 – 21

Standard Guide for Quantitative Measures for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics[1]

This standard is issued under the fixed designation F3518; 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 This guide provides quantitative measures for assessing one or more specific ergonomic parameters with respect to exoskeletons. Furthermore, this guide should be used in conjunction with Practice F3474, Guide F3519, and Standard Guide for The Application of Ergonomics to Prevent Injury During Exoskeleton Use[2].

1.2 This guide provides quantitative measures for the design, use, and construction of exoskeletons within the domains of industry, military, medical, first responders, and recreational.

1.2.1 Quantitative measures are a type of data that can be put into a numerical value. This type of measure allows statistical analysis to be performed on the data to yield an objective result.

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

F3474 Practice for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics

F3519 Guide for Establishing a Reporting Structure for Exoskeleton Analysis

3. Terminology

3.1 *Definitions:*

3.1.1 *dynamometer, n*—instrument that measures the force output of grip strength.

3.1.2 *electromyography, n*—recording of the electrical activity of muscle tissue using electrodes to the skin or inserted into the muscle belly.

3.1.3 *heart rate, n*—speed with which the heart beats, measured in the number of contractions of the heart over the course of a minute.

3.1.4 *heart rate variability, n*—variation of the time between each heartbeat, specifically, the variation of the "R" to "R" intervals of the heartbeat QRS component.

3.1.5 *kinematics, n*—branch of mechanics concerned with the motion of objects without reference to the forces that cause the motion.

3.1.6 *motion capture, n*—process or technique of recording patterns of movement digitally.

3.1.7 *non-invasive, adj*—not requiring the introduction of instruments into the body.

3.1.8 *oscilloscope, n*—device for viewing oscillations, as of electrical voltage or current, by a display on the screen of a cathode ray tube.

4. Significance and Use

4.1 This guide provides a set of recommended quantitative measures which can be used to assess the task or human readiness, or both, of exoskeletons. All of the quantitative measures are used in ergonomic research to assist in objectively concluding the efficacy of an assessed metric.

4.2 Not every element of this guide may be applicable to all exoskeleton components or configurations. Nor are all the quantitative measures herein exhaustive. Selection of quantitative measures should be done based on the uncertainties surrounding the end use application of the exoskeleton. It is the

[1] This guide is under the jurisdiction of ASTM Committee F48 on Exoskeletons and Exosuits and is the direct responsibility of Subcommittee F48.02 on Human Factors and Ergonomics.

Current edition approved June 15, 2021. Published July 2021. DOI: 10.1520/F3518-21.

[2] Unpublished ASTM standard under development.

[3] 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.

manufacturer's responsibility to determine which portions of this guide, and the corresponding measures, are applicable to their exoskeletons.

4.3 The ability to reproduce analysis between exoskeleton usage vs. non-exoskeleton usage is critical criteria in using a quantitative measures approach. A control method for reproducibility in a quantitative measures approach is a repeated measures design. A repeated measures design involves multiple measures of the same variable taken on the same end user, either under different conditions or over two or more time periods. The salient aspect of a repeated measures design is using the end user as the control.

5. Quantitative Measures

5.1 *Electromyography (EMG)*—EMG uses electrodes to measure the electrical activity of contracting skeletal muscles. There are several types of EMG depending on the type of electrodes used. Surface EMG (SEMG) traditionally uses surface electrodes for a non-invasive analysis of a muscle of interest. The muscle(s) of interest are those whose activations are anticipated to change due to use of the exoskeleton in comparison to the no-exoskeleton condition. (Activation of these muscles may be increased or decreased by the exoskeleton.) For example, the muscles of interest for an upper extremity exoskeleton include those involved in shoulder and upper arm movement. This assumes normally functioning muscles and does not account for neuromuscular degenerative pathologies (please seek a medical professional for appropriate implementation). Another type of electromyography is known as intramuscular electromyography. This is an invasive type of measurement because it uses fine-wire or needle electrodes that are inserted directly into the muscle. Because of its tiny surface area for recording electrical activity, intramuscular EMG allows for the assessment of individual motor units in the muscle of interest. Furthermore, fine-wire electrodes have a better signal-to-noise ratio than surface electrodes. However, fine-wire electrodes require special training and medical supervision to place the wires accurately and not damage the muscles during insertion and removal. For this reason, surface electrodes are recommended because of their non-invasive application.

5.1.1 *SEMG Analysis*—The SEMG percentage of maximum voluntary isometric contraction (MVIC) analysis is evaluated using a peak amplitude analysis. The reason SEMG is assessed through a percentage of MVIC is because SEMG is purely a measure of muscle activity (measured in microvolts) without correlation to a force metric (**1**)[4]. Once data are acquired, descriptive statistics may be used to summarize the results.

5.1.2 *Percent MVIC*—Percent MVIC is conducted by capturing three to five maximum voluntary contractions trials for 6 s periods of a specific muscle of interest with external resistance applied (**1**). Averaging of the middle 2 s of each trial is performed against the total number of trials. Thus, for a 6 s period, seconds 1 and 2 and 5 and 6 are dropped (**1**). Seconds 3 and 4 would be averaged. The user will then perform the specific task based on the required evaluation. The MVICs are then averaged, bandpass filtered, and a root mean square (RMS) is calculated to result in a single number for each assessed muscle. This number is applied to the bandpass-filtered RMS value of the task evaluation results to conclude a percent MVIC of the user's muscle exertion.

5.1.2.1 *Percent MVIC Reference Posture*—The postures, positions, or movement patterns, or combinations thereof, adopted to perform percent MVIC should correlate to the task that the user will perform. For example, if a task requires a user to perform a pointing task and the muscle of interest is the anterior deltoid, then the percent MVIC should not use any resistance for the isometric contraction. Rather, the task should be performed by the user flexing their arm anteriorly without bending their elbow. For example, if the task requires lifting cans of paint from one table to another, and the muscle of interest is still the anterior deltoid, then the user should perform a resisted isometric contraction against an immovable object (such as a wall).

5.1.3 *Muscle Fatigue*—Muscle fatigue is assessed by transforming the EMG signal from the time domain to the frequency domain. This is commonly done using fast Fourier transform (FFT) of the bandpass-filtered RMS EMG measured during the task. Moving from the time to frequency domain allows the assessment of the onset of muscle fatigue based on changes in firing rates of different muscle fibers. The two predominant skeletal muscle fibers are Type I fibers, which are fatigue resistant, while Type II fibers are fast fatiguing. Frequency ranges from Type I and II fibers are 10 to 250 Hz. As a conceptual example, a frequency plot is a graph of frequency on the *x*-axis against power (or muscle activity) on the *y*-axis. Muscle fatigue occurs when the median value of the frequency plot shifts from a higher value to a lower value (Fig. 1). This shift is caused by an increase in the firing rate of Type I fibers with a simultaneous decrease in firing of Type II fibers. Muscle fatigue assessments should evaluate frequency change over time rather than an average frequency per job task.

5.1.4 *SEMG Utilization*—A SEMG user baseline task is measured with the exoskeleton doffed. Next, the task is repeated with the exoskeleton donned. MVIC and fatigue are subsequently analyzed and compared between the baseline and exoskeleton task executions. The effect of the exoskeleton should be assessed by comparative analysis between these conditions, and the results should show that the exoskeleton changes the level of muscle exertion in the desired direction from the baseline measurement. Appropriate sampling and statistical method should be considered. For example, an exoskeleton designed for industrial use to support the shoulders should reduce the level of muscle exertion. Alternatively, an exoskeleton designed for medical use to improve a patient's strength may increase the level of muscle exertion. Generally, this is to ensure that the patient can use the medical product safely and effectively for the intended use and use environment.

For further detail on SEMG, please review the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) project (**2**) and Cram and Criswell (**1**). SEMG research requires a high level of training and control to

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