Designation: F3474 – 20

Standard Practice for Establishing Exoskeleton Functional Ergonomic Parameters and Test Metrics[1]

This standard is issued under the fixed designation F3474; 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 practice provides a recommended approach and a set of options for assessing one or more specific ergonomic parameters with respect to human users of exoskeletons.

1.2 This practice provides functional ergonomic criteria to consider for the design, production, and evaluation of exoskeletons within the domains of industry, military, medical, first responders, and recreational. When designing exoskeletons, natural unassisted human kinematics and kinetics, as well as the resulting strain and fatigue experienced by the user should be salient design parameters. Any changes in the natural unassisted human kinematics and kinetics may impact the exoskeleton's effectiveness in augmenting user performance. Therefore, the defining principle of this practice is to establish objective measures that can be selected from to assess human kinematics and kinetics, as well as the resulting strain and fatigue experienced by the user within the task context of the exoskeleton's end use application.

1.3 *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.*

1.4 *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. Significance and Use

2.1 This practice describes what measure should be performed during the near (hours/days), mid (days/weeks), and far (months/years) stages of exoskeleton evaluation (Fig. 1). The functional conditions and metrics with respect to each task method are assessed from the body area(s) impacted by the exoskeleton (for example, upper body, lower body, or both). These may be within as well as distant to the body areas impacted by the exoskeleton (for example, an upper body exoskeleton may have impacts on the trunk and spine). Desired effects as well as unintended encumbrances to the user's body are important considerations. The evaluation will occur within the context relevant to the end-use application of the exoskeleton's implementation. This practice pertains to the industry, military, medical, first responders, and recreational domains, but other domains may arise in the future and will need to be considered. Each domain is unique unto itself; however, the task methods and metrics collected may be unique or overlap across any number of user domains.

2.2 Task methods and their metrics are either administered in a laboratory environment, field environment, or both laboratory and field environments. Where not otherwise specified, patient functional outcome measures and pain are key metrics that should be considered for testing performed in the medical domain. Exoskeleton producers or researchers, or both, may also want to consider different types of imaging such as X-rays, computed tomography (CT) scans, magnetic resonance imaging (MRI), ultrasound, and nuclear medicine imaging. Additionally, exoskeleton producers or researchers, or both, may also wish to carry out neuroimaging such as, but not limited to, structural and functional and diffusion MRI, magnetoencephalography (MEG), electroencephalography (EEG), positron emission tomography (PET), or near infrared spectroscopy (NIRS) to understand the cognitive and neurophysiological impacts that exoskeletons have on the brain.

2.3 Fig. 2 is a Venn diagram that portrays the distinct interactions that may transpire between the user (human), exoskeleton, and task. The interactions are:

2.3.1 *Human*—For example, baseline health, physiology, and job duty assessment;

2.3.2 *Human with an Exoskeleton*—For example, fit, comfort, physical size changes, psychosocial considerations, cognitive load, training level, donning/doffing time, and safety;

2.3.3 *Human Performing Tasks*—For example, efficiency, speed, agility, power, strength, quality, mobility, time on task, and safety;

[1] This practice 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 Dec. 15, 2020. Published January 2021. DOI: 10.1520/F3474-20.

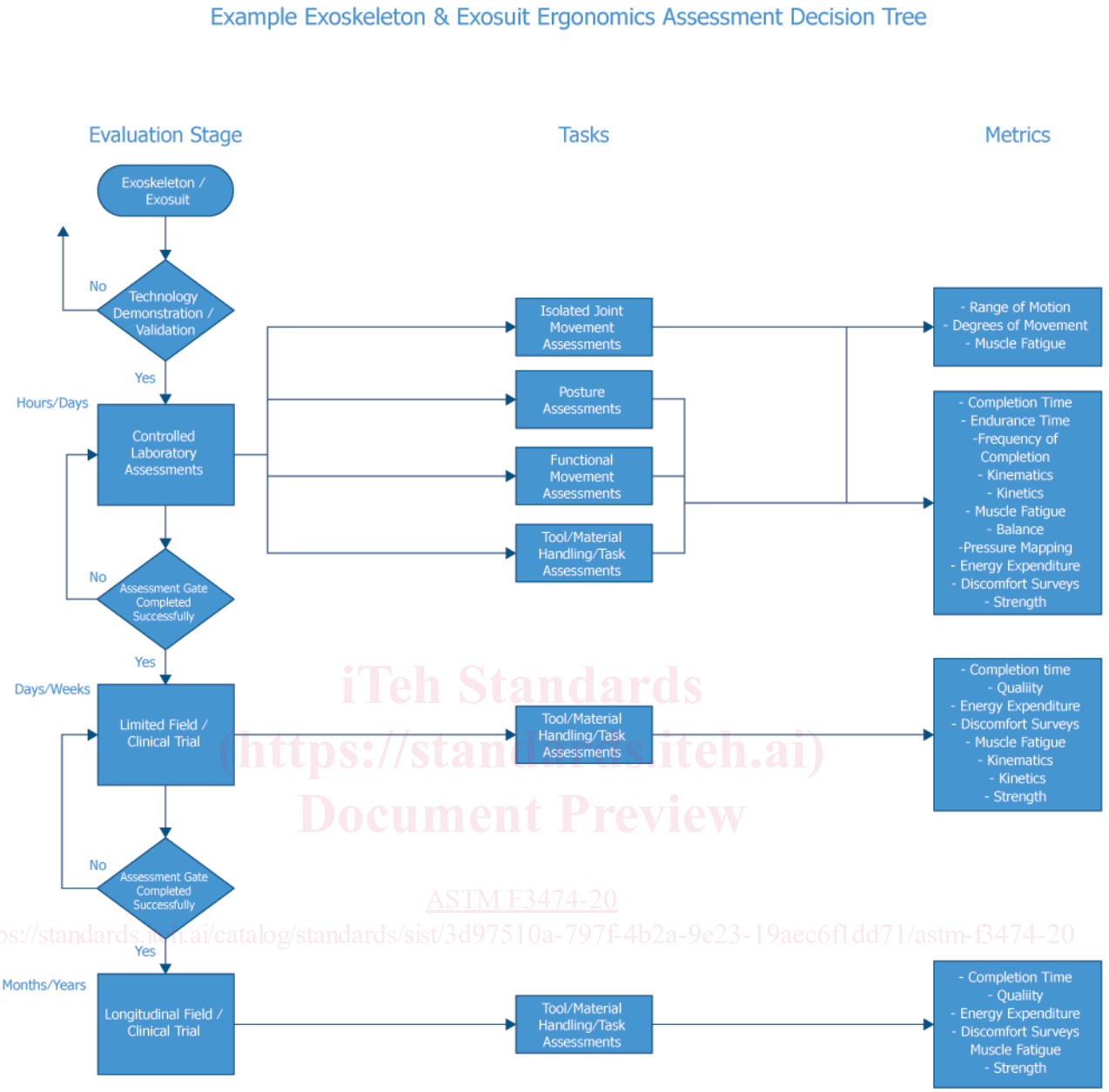

FIG. 1 Exoskeleton Assessment Decision Tree

2.3.4 *Human with an Exoskeleton Performing Tasks*—For example, efficiency, speed, agility, power, strength, quality, mobility, time on task, reliability, and safety;

2.3.5 *Exoskeleton (Exo)*—For example, failure mode and effects analysis; material strength and quality; safety factors; cybersecurity; morphological characteristics such as size, shape, and weight; hygiene; cleanliness; integrity; readiness; and durability;

2.3.6 *Exoskeleton Performing Tasks*—For example, an automated setup to test mean time between failure, environmental conditions, fatigue and fracture, power usage, or compatibility with other equipment;

2.3.7 *Tasks*—A catalog of events either occupational or recreational that a user performs;

2.3.8 *Organization (Org)*—The framework within which the user carries out tasks (for example, home, office, and hospital—the users shall adapt to their organization);

2.3.9 *Tools/Equipment*—All the technological means, raw materials, and products made available to the user to conduct a work task. The user uses different kinds of tools, no matter what the context, be it private, professional, or medical; and

2.3.10 *Environment (Env)*—Constitutes the physical and social atmosphere of the place of the exoskeleton's use. The external context at the time of the events when the user carries out the task (for example, indoors, outdoors, constrained space (for example, tanks), dirty, humid, hot, cold, dry, wet, and slippery).

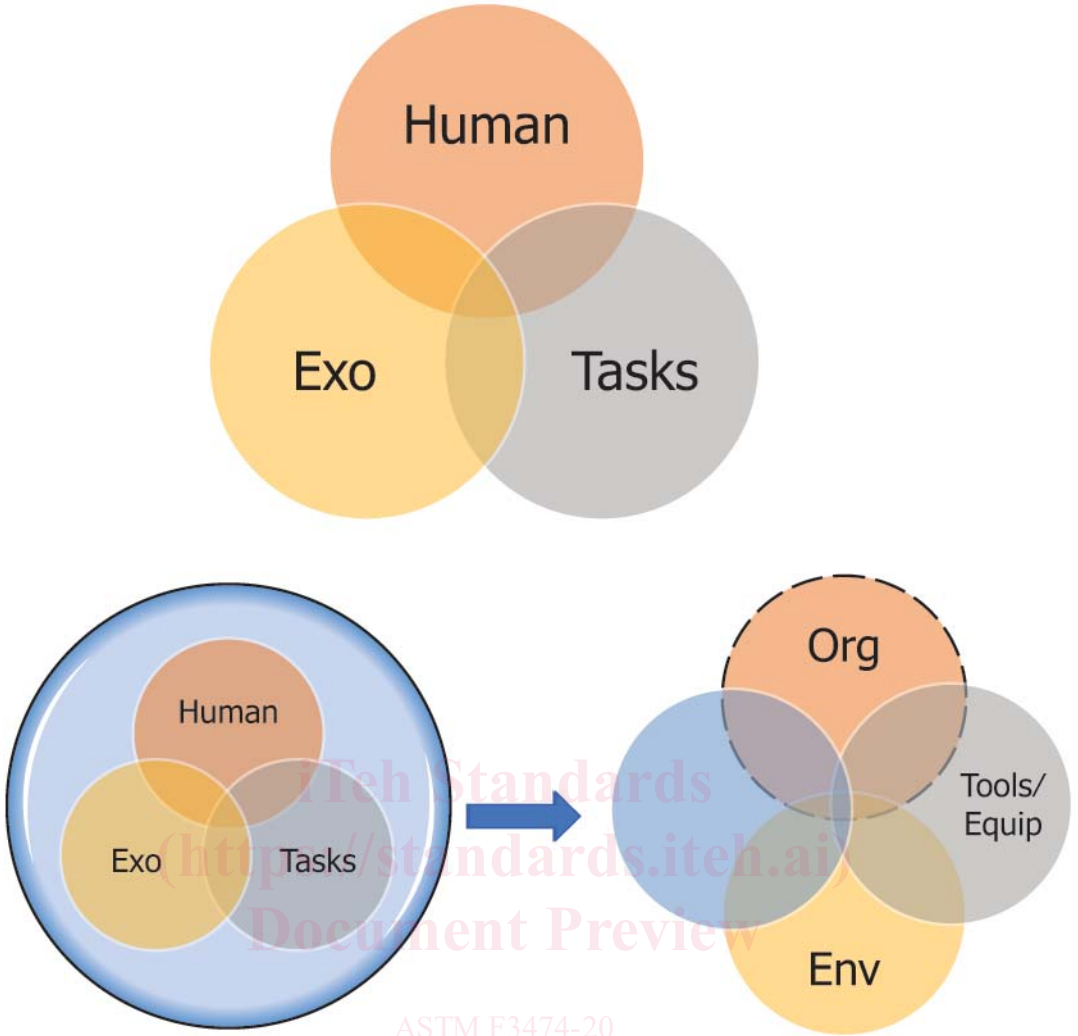

FIG. 2 Exoskeleton Performance Interaction Diagram

2.4 This methodology indicates considerations that employers/users should use to govern which jobs are more suited to just humans versus humans with exoskeletons. Based on those results, human exoskeleton assessments can be performed using the ergonomic assessment decision chart to determine exoskeleton efficacy with respect to the task(s). From there, the human, exoskeleton, and task(s) are integrated into the organization (where applicable based on domain), tools/equipment, and environment of utilization. Furthermore, when conducting an assessment, please see Practice for Documenting Environmental Conditions for Utilization with Exoskeleton Test Methods for environmental ramifications.[2]

2.5 Depending on the context in which the exoskeleton is used (medical, industrial, military, first responders, and recreational), it is necessary to take into account these complementary characteristics to integrate the exoskeletons better.

3. Ergonomic Assessment Decision Chart

3.1 Fig. 1 is a decision tree that categorizes the evaluation stages, tasks, and metrics for the objective assessment of an exoskeleton. The decision tree is modulated temporally in which assessments occur at hours/days, days/weeks, and months/years. This decision tree complements the task methods in Section 4 with respect to when an assessment should be conducted.

4. Ergonomic Task Methods

4.1 *Isolated Joint Movement:*

4.1.1 *Passive Joint Range of Motion*—Passive joint range of motion can be applicable throughout the body. Passive range of motion is the arc of motion produced by the application of an external force by an examiner, gravity, or external source. These changes reflect angular displacements unique to the respective joint. Assessments of passive joint range of motion can be conducted in a laboratory or field environment associated with the industrial, military, medical, first responders, and recreational domains. Such measures are degrees of movement, range of motion, and strength assessments. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (rating of pain, soreness, discomfort, or comfort, or combinations thereof).

[2] Unpublished ASTM standard in development.

4.1.2 *Active Joint Range of Motion*—These changes reflect angular displacements unique to the respective joint. Active range of motion is the arc of motion produced by an individual's voluntary unassisted muscle contraction, joint mobility, and the resultant movement of part(s) of the body. Assessments of active joint range of motion can be conducted in a laboratory or field environment associated with industrial, military, medical, first responders, and recreational domains. Objective measures are electromyography, degrees of movement, range of motion, and strength assessments. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (rate of perceived exertion (RPE), rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.1.3 *Workspace or Reach Envelope*—Workspace or reach envelope affords two- and three-dimensional (2 and 3D) joint or limb range of motion (for example, movement through one or multiple planes) of the upper and lower body extremities. Assessments of a workspace or reach volume can be conducted in a laboratory or field environment associated with industrial, military, medical, first responders, and recreational domains. The envelope is quantified by a workspace volume, which is measured quantitatively in cubic measurements.

4.2 *Posture and Movement:*

4.2.1 *Standing Balance Assessment*—Standing balance assessment is bifurcated between static and dynamic analyses. This assessment is applicable to the entire body. Assessments of standing balance assessment can be conducted in a laboratory or field environment associated with the industrial, military, medical, first responders, and recreational domains.

4.2.1.1 *Static Standing Balance*—Static standing balance can either be symmetrical, staggered, split, tandem, or single-leg stance. Objective measures are center of pressure muscle activation/fatigue (electromyography (EMG), integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and maximal oxygen uptake (VO_2) max), blood pressure, blood-oxygen saturation, near infrared spectroscopy, motion capture, postural sway, center of gravity, and pressure mapping. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.2.1.2 *Dynamic Standing Balance*—Dynamic standing balance can be assessed using equipment such as balance boards, balance beams, and incline/decline slopes. It can be assessed in symmetrical, staggered, split, tandem, or single-leg stance. Objective measures are blood pressure, blood-oxygen saturation, center of pressure, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), blood pressure, blood-oxygen saturation, near infrared spectroscopy, motion capture, center of gravity, postural sway, pressure mapping, and completion time. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). A measure to account for incidents of falls or loss of balance is important for industrial, military, medical, first responders, and recreational domains.

4.2.2 *Seated Task*—Seated task covers a chair, bench, or stool without a back; chair, bench, or stool with a back; and using the ground as a seating surface. Assessments of a seated task can be conducted in a laboratory or field environment associated with industrial, military, medical, first responders, and recreational domains. Seated tasks encompass the entire body.

4.2.2.1 *Seated With or Without a Chair Back*—Seated with or without a chair back objective measures are blood pressure, blood-oxygen saturation, durations of maintaining the posture, ability to obtain the posture, seated stability (center of pressure), muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, functional completion, joint/spine stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), postural sway, and 3D changes of body segments and limbs. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.2.2.2 *Seated on the Ground*—Seated on the ground objective measures are blood pressure, blood-oxygen saturation, durations of maintaining the posture, ability to obtain the posture, seated stability (center of pressure), muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, functional completion, joint/spine stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), postural sway, and 3D changes of body segments and limbs. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.2.3 *Awkward Postures*—Awkward postures can be described as non-neutral postures. Non-neutral postures place the user's body in positions of misalignment. Upper body areas specific to misalignment are the neck, shoulder, elbow, forearm, wrist, and hand. Awkward postures can also apply to the trunk/torso, spine, pelvis, hips, knees, ankles, and feet. These misalignments can increase strain on the surrounding tissues and can cause uneven wear and eventual potential damage to soft tissues and joints. When awkward postures are sustained over extended durations, reduced blood flow to tissue

often results, which can exacerbate suboptimal conditions for the user at a greater rate. Wear of an exoskeleton may increase, decrease, or affect in a different manner the frequency and duration of the awkward posture. Assessments of awkward postures can be performed in both laboratory and field environments associated with industrial, military, medical, first responders, and recreational domains. Objective measures are duration of maintaining the posture, the ability to obtain the posture, blood pressure, blood-oxygen saturation, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, functional completion/effectivity tasks, joint/spinal stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), 3D volumetric changes of body segments/limbs, and pressure points. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). All domains leverage functional completion/effectivity, and military and law enforcement should consider weapons and armor.

4.2.3.1 *Lying Prone or Supine*—Lying prone or supine affects the entire body segments of exoskeleton users. Assessments of lying prone or supine can be conducted in laboratory or field environments associated with industrial, military, medical, first responder, and recreational domains. Objective measures are heart rate, heart rate variability, blood pressure, blood-oxygen saturation, duration of maintaining the posture, ability to obtain the posture, heart rate variability, functional completion/effectivity tasks, joint/spinal stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), 3D volumetric changes of body segments/limbs, and pressure points. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). All domains may include functional completion/effectivity and completion times, and military and law enforcement should consider weapons and armor.

4.2.3.2 *Neck*—The neck encompasses only head movement. This task's context is flexion (anterior movement), extension (posterior movement), side bending (lateral movement), and rotation at the cervical vertebrae where the torso is static or representative of the task under evaluation. Neck assessments can be conducted in a laboratory or field environment associated with industrial, military, medical (patient centric), first responder, and recreational domains. Objective measures are relative movement between helmet and head, range of motion, binary task completion, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, duration/frequency of maintaining the posture, postural stability, and postural recovery (returning back to neutral posture). Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Lastly, all domains should be concerned with quality of movement.

4.2.3.3 *Torso*—The torso encompasses the entire body. This task's context is flexion (anterior movement), extension (posterior movement), rotation, and side bending (lateral movement) at the trunk where the feet are planted and the lower body is mostly static. Torso assessments can be conducted in a laboratory or field environment associated with industrial, military, medical (patient centric), first responder, and recreational domains. Objective measures are range of motion, binary task completion, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, duration/frequency of maintaining the posture, postural stability, and postural recovery (returning back to neutral posture). Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, for all domains, functional completion/effectivity are significant, and military and law enforcement should consider weapons and armor. Lastly, the medical domain is concerned with quality of movement, functional outcome measures, and pain capture.

4.2.4 *Kneel*—A kneel, either with single or double knee involves the trunk/torso and lower body. Tasks may be performed in kneeling that also involve the upper body. Assessments of a kneel can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are blood pressure, blood-oxygen saturation, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, duration of maintaining the posture, ability to obtain the posture, kneeling stability (center of pressure), heart rate variability, functional completion/effectivity tasks, joint/spinal stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), postural sway, and 3D volumetric changes of body segments/limbs. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, for all domains, functional completion/effectivity and completion times are of significance, and military and law enforcement should consider weapons and armor.

4.2.5 *Shoulder Mobility*—Shoulder mobility mainly encompasses the upper body and the trunk/torso. The shoulder is a very mobile joint. When shoulder mobility is tested while the user performs a task involving the lower body, the lower body may also be of interest. This task's context is moving forward (flexion), backwards (extension), sideways (abduction and adduction), and rotating (internally and externally) at the shoulder. Internal and external rotation can be completed with the shoulder maintained in any range of motion. Finally, the evaluation can integrate horizontal abduction, horizontal adduction, or circumduction. Assessments of shoulder mobility can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, and duration/frequency of maintaining the posture, postural stability, and postural recovery (returning back to neutral posture). Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.2.5.1 *Arms at or Above Shoulder*—The arms above shoulders movement mostly applies to the upper body and trunk/torso, although tasks may be performed involving this posture in standing which also involved the lower body. This task area delineates overhead work, hands or arms would be above shoulders and the torso would be upright. Assessments of arms above shoulders can be conducted in a laboratory or field environment associated with industrial, military, medical, first responders, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), blood pressure, blood-oxygen saturation, metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity/accuracy/precision tasks, duration/frequency of maintaining the posture, and strength assessment. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, for all domains functional completion/effectivity and completion times are significant and should be considered, and military and law enforcement should consider weapons and armor.

4.2.6 *Squat*—A squat encompasses the entire body. Assessments of a squat can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, and duration/frequency of maintaining the posture. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, for all domains, functional completion/effectivity and completion times are significant and should be considered, and military and law enforcement should consider weapons and armor.

4.2.7 *Stoop or Bend*—Stoop or bend involves the entire body. The legs during this task are fairly straight and the trunk/torso and upper body are bending at the waist. Assessments of a stoop or bend can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, completion times, and duration/frequency of maintaining the posture. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, military and law enforcement should consider weapons and armor.

4.2.8 *Forward Lunge*—Forward lunge involves the entire body. The foot position is one foot in front of the other at a set length (staggered or split stance). Assessments of a forward lunge can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2

max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, completion times, and duration/frequency of maintaining the posture. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, military and law enforcement should consider weapons and armor.

4.2.9 *Sideways Lunge*—A sideways lunge involves the entire body. The foot position is one foot beside the other at greater than shoulder length apart (staggered). Assessments of a sideway lunge can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, completion times, and duration/frequency of maintaining the posture. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (rate of perceived exertion (RPE), rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, military and law enforcement should consider weapons and armor.

4.2.9.1 *Hip Mobility*—Hip mobility mainly encompasses the lower body and the trunk/torso. The hip is a very mobile joint. When hip mobility is tested while the user performs a task with the upper body, the upper body may also be of interest. This task's context is moving forward (flexion), backwards (extension), sideways (abduction and adduction), and rotating (internally and externally) at the hip. Internal and external rotation can be completed with the hip maintained in any range of motion. Finally, the evaluation can integrate horizontal abduction, horizontal adduction, or circumduction. Assessments of hip mobility can be conducted in a laboratory or field environment associated with industrial, military, medical, first responder, and recreational domains. Objective measures are range of motion, binary task completion, 3D volumetric changes of body segments/limbs, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), metabolic/energy cost (rate of oxygen consumption, kilocalories expended, cost of transport, heart rate, heart rate variability, respiratory exchange ratio, and VO_2 max), NIRS, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, and duration/frequency of maintaining the posture, postural stability, and postural recovery (returning back to neutral posture). Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (rate of perceived exertion (RPE), rating of pain, soreness, discomfort, or comfort, or combinations thereof).

4.3 *Functional Movement:*

4.3.1 *Posture Transitions*—Posture transitions includes the entire body with respect to user movements from prone to supine, supine to prone, prone or supine to sitting, prone or supine to a kneel, sitting to kneeling, sit to stand, kneel to stand, or some combination of these postures. This task's context involves dynamic changes of multiple joint angles and center of gravity as the user transitions between postures. Assessments of posture transitions can be conducted in a laboratory or field environment associated with industrial, military, medical (patient centric), first responder, and recreational domains. Objective measures are blood pressure, blood-oxygen saturation, range of motion, binary task completion, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), NIRS, heart rate, heart rate variability, joint/spinal stresses (biomechanics), skin interface (shear, pressure, friction, and thermal), functional completion/effectivity tasks, postural stability, and completion time. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, military and law enforcement should consider weapons and armor. Lastly, all domains are concerned with quality of movement.

4.3.2 *Hand Grip*—Hand grip encompasses only the upper body unless grip is being assessed in conjunction with a task that also involves the trunk/torso and lower body. This task's context involves varying postures of the hand. Assessments of hand grip can be conducted in a laboratory or field environment associated with industrial, military, medical (patient centric), first responder, and recreational domains. Objective measures are duration of maintaining the posture, ability to obtain the posture, heart rate, heart rate variability, muscle activation/fatigue (EMG, integrated muscle activity, time of muscle activity onset, frequency component analysis, muscle synergies, or co-contraction, or combinations thereof), NIRS, functional completion/effectivity tasks, joint stresses (biomechanics), binary fit changes, skin interface (shear, pressure, friction, and thermal), 3D volumetric changes of body segments/limbs, pressure points, and strength evaluation. Subjective measures as the user performs the task are psychophysical and psychophysiological metrics (RPE, rating of pain, soreness, discomfort, or comfort, or combinations thereof). Additionally, military and law enforcement should consider weapons and armor.

4.3.3 *Walk*—Walk encompasses the entire body. This task's context involves terrain of varying slope: level, cross slopes, incline, and decline. Further, walking direction (forward, backward, sidestepping, and combinations of directions) is relevant. Lastly, different types of environments such as over ground, treadmill, rock, gravel, sand, snow, ice, and water should be considered. Assessments of walking can be conducted in a laboratory or field environment associated with industrial, military, medical (patient centric), first responder, and recreational domains. Objective measures are blood