Validation & Scientific Evidence

Scientific Foundation • Verification • Validation • Application Evidence

A consolidated evidence document for SoldierSim™ and the Santos human digital twin technology base

iHuman Technology Corporation

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1. Executive Summary

SoldierSim is built on a long-running scientific program in digital human modeling, predictive dynamics, biomechanics, ergonomics, physiology, strength, fatigue, stability, vision, equipment interaction, and survivability. The supplied archive contains 341 source files across 24 supplied collections/items, representing 272 unique base filenames after duplicate filenames and alternate copies are removed. The collection includes peer-reviewed journal papers, conference papers, theses, dissertations, technical reports, validation studies, and program reports.

The evidence is not a single validation experiment. It is a validation journey: mathematical formulation and component development; formal validation-method development; direct comparison of predicted motion with human motion-capture data; comparison of force and biomechanical quantities; validation of individual scientific submodels; and application-specific studies involving military tasks, load carriage, armor, visibility, and human performance.

CENTRAL FINDING

The strongest claim supported by the supplied archive is that Santos/SoldierSim rests on a broad, multi-decade, independently documented scientific foundation with multiple layers of validation. Direct task-level validation has demonstrated meaningful agreement for several locomotion and military-relevant tasks, while the studies also document task-dependent discrepancies, human strategy variability, and areas requiring continued refinement.

Evidence categories

Evidence level	Meaning	Examples in supplied archive
A. Direct task validation	Predicted task output compared with measured human data using motion capture, force data, statistical analysis, or task determinants.	Walking, stair climbing, box lifting, vertical jump, box jump, ladder climbing, stand-to-prone, prone-to-stand.
B. Component / submodel validation	A scientific component is developed and tested against experimental or published data.	Biomechanics, strength surfaces, fatigue, posture prediction, vision measures, head-neck strength.
C. Scientific-method evidence	Peer-reviewed formulation and development of the mathematical and computational methods underlying prediction.	Predictive Dynamics, Hybrid Predictive Dynamics, optimization, inverse kinematics, ZMP/stability, motion planning.
D. Application evidence	Demonstration of methods on real design or military problems.	Soldier aiming/kneeling/prone tasks, equipment interaction, armor optimization, load carriage, survivability.

What this document is - and is not

- This is a structured scientific-evidence summary based on the supplied archive, not a claim that every SoldierSim output has been validated for every task, anthropometry, load, or environment.
- Direct validation results are reported with the strengths and limitations described by the original studies.
- Application papers demonstrate scientific breadth and operational relevance but are not automatically treated as independent validation studies.
- Additional publications, customer reports, and newer validation results can be incorporated into future revisions.

2. Evidence Base Reviewed

Archive supplied	Files	Primary evidence domain
Predictive Dynamics	63	Predictive Dynamics, Hybrid Predictive Dynamics, walking, running, lifting, stairs, ladder, military tasks, equipment interaction.

Archive supplied	Files	Primary evidence domain
Human Performance - Dynamics/Physics based	29	Physics-based human movement prediction and task applications.
Theses and Dissertations	18	Foundational research in predictive dynamics, posture, optimization, physiology, fatigue, grasping, clothing, reachability.
Human Load Stability Balance	17	ZMP, balance, loading, carrying, gait, soldier motion.
Hand Modeling and Grasping	16	Hand model, grasp prediction, force/torque, ergonomic grasp applications.
Validation	16	Formal validation methodology and direct task validation studies.
Biomechanics Modeling	13	Biomechanical formulation, joint coupling, strength surfaces, model validation.
Strength - Fatigue - Muscles	12	Strength, muscle force, fatigue, head-neck strength.
HPD to send	11	Hybrid Predictive Dynamics and advanced task prediction.
Survivability-PPE-Armor	9	Armor design, internal organs, survivability and task-based PPE applications.
Thermal	6	Physiology, thermal modeling, energy adjustment, substrate depletion.
Vision	5	Vision-performance measures and visibility constraints/objectives.
Behavior	2	Behavior generation, strategy variation, performance-driven behavior.
Cloth Modeling - soft tissue	15	Clothing/armor mechanics, contact, deformation, soft-tissue representation.
Human Factors and Ergonomics	22	Ergonomics, vehicle layout, lifting, reach, discomfort, task-based design.
Human mass and inertia estimation	2	Subject-specific body-segment mass, center of mass, inertia, body-surface assessment.
Human modeling Overview	13	Integrated Santos architecture and digital-human modeling foundations.
Human Motion and path planning	25	Motion prediction, model predictive control, obstacle avoidance, gait and path planning.
Human Vibration	11	Whole-body vibration response, discomfort, seated/supine response, experimental frameworks.
Injury Prediction	7	Musculoskeletal injury prediction and repetitive-loading assessment.
Physiology	4	Extended load carriage, female physiology, cardiovascular, hydration and thermal response.
Posture - IK	9	Inverse kinematics, posture prediction, multi-objective optimization and validation.
Workspace analysis	15	Reach envelopes, workspace boundaries, zone differentiation and layout design.
Dual-arm dynamics paper	1	Dual-arm dynamic motion prediction and joint constraint force/moment prediction.

Note: The archive contains duplicate papers and alternate copies across thematic folders. Counts above describe the supplied files, not a count of distinct peer-reviewed publications.

Representative cornerstone works

Year	Representative work	Evidence contribution
2005-2006	Foundational theses and early optimization/posture/predictive-dynamics studies	Established posture prediction, multi-objective optimization, muscle/strength, physiology, grasping, reachability, and early predictive-dynamics concepts.
2007-2009	Formal predictive-dynamics and validation framework publications	Established task-based validation methods and expanded prediction to walking, lifting, running, stairs, stability, and vision.
2009-2013	Predictive Dynamics / Hybrid Predictive Dynamics	Published optimization-based dynamic prediction, strength surfaces, military task

Year	Representative work	Evidence contribution
	maturation	prediction, ladder climbing, jumping, and equipment interaction.
2015	Dedicated task-validation campaign	Vertical jump, box jump, ladder climbing, stand-to-prone, and prone-to-stand measured against human motion-capture data under weighted and unweighted conditions.
2014-2018	Survivability, PPE, and internal-anatomy applications	Expanded digital-human use to armor optimization, hit detection, internal organs, and survivability.
2022+	Soldier task / fitness modeling and continuing model development	Connected digital-human task demands to soldier physical-performance metrics and continued component refinement.

3. Scientific Architecture Supporting SoldierSim

The scientific basis represented in the archive is best understood as a layered system. SoldierSim is the application layer; Santos provides the digital-human representation and predictive capability; and the underlying research provides the mathematical, biomechanical, physiological, and validation foundations.

Layer	Scientific role	Representative evidence
Digital human representation	Anthropometry, kinematics, joint structure, skeletal constraints, body geometry.	Posture-prediction theses; biomechanics papers; shoulder coupling; hand model; clothing and reachability work.
Prediction engine	Optimization-based prediction of posture and motion without requiring a prerecorded motion for each new condition.	Predictive Dynamics; Hybrid Predictive Dynamics; trajectory planning; inverse kinematics; multi-objective optimization.
Dynamics & biomechanics	Joint torques, external forces, ground reaction forces, dynamic equilibrium, energy-related quantities.	Walking/running/lifting/stair papers; Santos biomechanics validation; recursive dynamics methods.
Human capacity	Strength surfaces, muscle force, fatigue, pain/exertion relationships.	Knee/elbow 3D strength surfaces; upper-limb musculoskeletal model; fatigue thesis; head-neck strength work.
Stability & interaction	Balance, ZMP, load interaction, collision avoidance, equipment interaction.	ZMP research; load-carrying studies; equipment-interaction studies; soldier prone/aim prediction.
Physiology & environment	Energy expenditure, thermal and physiological effects, work capacity.	Physiology writeups, thermal model synopsis, critical power, substrate depletion, energy adjustment.
Perception & task constraints	Vision, aiming, end effectors, workspace and reach.	Vision-performance papers; aiming/kneeling soldier studies; workspace and reachability theses.
Validation framework	Task determinants, motion-capture comparison, statistical metrics, confidence intervals, force comparisons.	Marler validation methodology; Rahmatalla validation protocol/framework; task-specific validation reports.

Illustrative SoldierSim application interface. Scientific modules are integrated into a customer-facing engineering workflow.

4. Predictive Dynamics: Core Scientific Foundation

A central scientific differentiator is Predictive Dynamics: an optimization-based framework for predicting human motion when both motion and applied forces may be unknown. In the foundational publication "Predictive dynamics: an optimization-based novel approach for human motion simulation," Xiang, Chung, Kim, Bhatt, Rahmatalla, Yang, Marler, Arora, and Abdel-Malek describe a formulation in which kinematic and kinetic quantities are optimization variables, equations of motion are enforced as equality constraints, and performance measures and task constraints guide the solution. The paper demonstrates the method on both a simple analytical problem and a full 3D human walking task. [PD-1]

Why this matters for SoldierSim

- Prediction can be formulated around task goals, human capability, physics, and constraints rather than relying only on playback of prerecorded motion.
- Changes in equipment, mass, center of gravity, task geometry, anthropometry, or environment can be introduced as changes to the model or constraints.
- The framework supports engineering questions that are difficult or expensive to answer by physically testing every configuration.

Scientific progression represented in the archive

Research progression	Examples
Foundational optimization and dynamics	Predictive Dynamics theses; multi-objective optimization; trajectory planning; dynamics sensitivity analysis.
Human locomotion	Walking, asymmetric gait, running, walk-to-run transition, backward walking.

Research progression	Examples
Vertical and constrained movement	Stair ascent/descent, ladder climbing, vertical jump, platform/box jump.
Object interaction	Box lifting, carrying symmetric/asymmetric loads, push-pull, equipment interaction.
Military-relevant tasks	Stand-prone-aim, aiming, kneeling, rifle collision avoidance, soldier task prediction.
Hybrid formulation	Hybrid Predictive Dynamics papers and stair-climbing applications combining prediction with measured-motion information where useful.

EVIDENCE INTERPRETATION

Predictive Dynamics publications establish the mathematical and scientific basis for prediction. They should be distinguished from direct validation studies, which separately ask how closely predicted task behavior matches measured human behavior.

5. Biomechanics, Kinematics, and Joint Mechanics

The archive contains a substantial body of work on biomechanical modeling, including joint constraint forces, shoulder coupling, inverse kinematics, dynamic equations, and strength. A dedicated paper titled “Validation of Santos biomechanics” is included in the biomechanics collection, and the direct locomotion-validation literature also compares joint-angle trajectories, ground reaction forces, inertia-related quantities, and task determinants. [BIO-1] [VAL-4]

Key scientific capabilities supported

- Kinematic representation of a high-degree-of-freedom human model.
- Joint-angle and posture prediction under task and environmental constraints.
- Joint torque and reaction-load calculations.
- Ground-reaction-force analysis for dynamic tasks.
- Spine shear/compression and task-specific biomechanical quantities.
- Shoulder-complex coupling and upper-body biomechanics.
- Optimization-based inverse kinematics with multiple end effectors.

Strength surfaces

Frey-Law and colleagues published “Knee and Elbow 3D Strength Surfaces: Peak Torque-Angle-Velocity Relationships” in the Journal of Applied Biomechanics. The study measured 54 participants and characterized peak torque as a function of joint angle and movement velocity. It found meaningful differences between flexion/extension and between joints, while normalized surfaces did not differ between men and women in that study. These experimentally derived strength relationships are representative of the type of empirical human-capability data used to ground digital-human analysis. [STR-1]

6. Strength, Muscle Capacity, and Fatigue

Soldier performance is not solely a geometric or kinematic problem. The evidence archive includes research on muscle force and activation, joint strength surfaces, fatigue, pain/exertion relationships, upper-limb musculoskeletal modeling, and head-neck strength. This provides a scientific basis for moving beyond “can the avatar reach?” toward “what physical demand does the task impose?”

Evidence area	Representative source	Contribution
Joint strength surfaces	Knee and Elbow 3D Strength Surfaces: Peak Torque-Angle-Velocity Relationships	Experimental mapping of strength as a function of joint angle and movement velocity. [STR-1]
Fatigue prediction	Modeling and validating joint based muscle fatigue due to	Development and validation of joint-based fatigue models

Evidence area	Representative source	Contribution
	isometric static and intermittent tasks - John Looft	against endurance/torque-decline data. [STR-2]
Upper limb	A musculoskeletal model of the upper limb	Musculoskeletal representation for upper-extremity loading/capacity. [STR-3]
Head/neck	ONR Head and Neck Final Report; Head-Neck Strength update	Head/neck strength and load-related model development relevant to helmets and head-supported equipment. [STR-4]
Exertion / pain	Relationships between Maximum Holding Time and Ratings of Pain and Exertion...	Empirical relationship between task duration, pain, exertion, and fatigue-related response. [STR-5]

RELEVANCE TO EQUIPMENT EVALUATION

Equipment changes that alter posture, load distribution, head-supported mass, joint torque, or task duration can be evaluated against human-capacity models rather than being treated only as changes in geometry.

7. Stability, Balance, and Load Interaction

The archive contains a dedicated body of work on zero-moment-point (ZMP) formulations, whole-body motion generation, load carrying, asymmetric loads, foot placement, lifting, and transitions. This scientific stream is important to SoldierSim because load carriage and soldier-worn equipment alter center of mass, balance strategy, ground reaction, joint demand, and movement.

Representative evidence

- “Efficient ZMP formulation and effective whole-body motion generation for a human-like mechanism” develops stability-related motion generation. [STAB-1]
- “Human carrying simulation with symmetric and asymmetric loads using optimization” addresses load effects on predicted motion. [STAB-2]
- “Optimization-based dynamic 3D human running prediction - effects of foot location and orientation” examines how contact placement influences predicted movement. [STAB-3]
- Walking, stair, ladder, lifting, and military-task studies apply the same broader dynamics/stability framework to increasingly complex tasks.

Illustrative SoldierSim load-carriage / human-performance visualization.

8. Physiology, Energy, and Thermal Evidence

The supplied thermal and physiology collection includes a Santos physiology writeup, energy-adjustment documentation for ETOWL, critical-power modeling, substrate-depletion modeling, a transient thermal-model synopsis, and a USARIEM manual. These materials document the scientific effort to represent human performance beyond joint mechanics.

Capability area	Supplied evidence	Role in SoldierSim / Santos
Energy expenditure	Energy Adjustment in ETOWL; dynamic motion simulation and energy expenditure prediction	Links mechanical/dynamic task demands to energetic consequences.
Physiology	Physiology in Santos - Writeup; Physiology thesis	Supports human-performance outputs beyond motion alone.
Thermal response	Transient thermal model of the human body synopsis; USARIEM manual	Provides scientific basis for environmental and heat-related analysis.
Work capacity	Critical Power Model	Supports sustained-performance / endurance representation.
Fuel / depletion	Substrate Depletion final	Represents physiological depletion during extended activity.

The supplied materials support the existence and scientific development of these models; the degree of direct validation varies by submodel. Accordingly, individual customer claims should identify whether an output is directly validated, calibrated from published data, or a model-based engineering estimate.

9. Hand, Grasping, Reach, and Vision

Hand and grasping

The hand-modeling archive includes a virtual human hand, compliant hand mechanisms, grasp prediction and analysis, joystick ergonomics, lifting with virtual human hands, and a PhD dissertation on grasping. These studies expand the digital human from whole-body movement into detailed object interaction, force/torque considerations, and ergonomic grasping. [HAND-1] [HAND-2]

Vision and visibility

The vision archive includes “Vision Performance Measures for Optimization-Based Posture Prediction” and related studies treating visibility both as a constraint and as an objective in posture prediction. The work introduced visual-performance measures and explored how visual requirements influence predicted posture. [VIS-1]

MILITARY RELEVANCE

Hand and vision research supports use cases such as weapon handling, aiming, eye relief, control interaction, equipment placement, and visibility-sensitive posture evaluation.

10. Survivability, PPE, and Armor Evidence

A separate research stream focuses on survivability and protective equipment. The archive includes digital human modeling for optimal body armor design, task-based survivability, hit detection, dynamic internal anatomy, internal viscera, and ONR/STTR final reports. This evidence demonstrates that the Santos research program extended beyond general ergonomics into military survivability and PPE design problems.

Research topic	Representative source	Engineering significance
Body armor optimization	Digital human modeling for optimal body armor design	Combines human/task considerations with armor-design evaluation and optimization. [ARM-1]
Task-based survivability	Digital human modeling capabilities for task-based survivability	Connects protective-system evaluation to task posture and human configuration. [ARM-2]
Internal anatomy	Digital Human Model Internal Organs; Simulating internal Viscera; Dynamic motion of internal anatomy	Extends the digital human to internal-anatomy representation for survivability analysis. [ARM-3]
Hit detection	DSTL Hit Detection	Supports geometry/task-specific survivability assessment. [ARM-4]
Program evidence	STTR N00014-11-M-0287 and N00014-13-C-0161 final reports	Documents funded research programs and development progression. [ARM-5]

11. Validation Methodology

Validation was treated as a research problem in its own right. The supplied archive contains multiple papers devoted specifically to validation methodology, protocols, frameworks, metrics, and statistical comparison. This is important because a predictive digital human can produce plausible-looking motion that is not necessarily quantitatively representative of human behavior.

Formal methodology development

- Marler et al., “Validation Methodology Development for Predicted Posture,” describes a systematic approach, experimental protocol, aggregation tools, and metrics for validating predicted postures. The authors explicitly distinguish subjective validation of strategy from objective validation with expected error margins. [VAL-1]
- Rahmatalla et al., “A Validation Protocol for Predictive Human Locomotion,” presents a task-based validation framework comparing selected motion determinants between Santos predictions and human motion-capture data. The protocol includes normalization of time histories, qualitative and quantitative comparison, B-spline fitting, confidence intervals, and ANOVA. [VAL-2]
- Rahmatalla and colleagues also developed validation frameworks for lower-body posture prediction and Santos biomechanics, extending the methodology beyond one task. [VAL-3] [VAL-4]

Validation principles evident across the archive

1. Define task-relevant determinants rather than comparing animation appearance alone.
2. Collect human experimental data under controlled conditions.
3. Normalize or align time histories when task duration differs among subjects.
4. Compare predicted and experimental joint trajectories and, where available, kinetic measures.
5. Use statistical methods and confidence intervals to quantify agreement and human variability.
6. Document discrepancies and use them to improve models and constraints.
7. Repeat validation as task complexity and model capability increase.

12. Direct Task-Level Validation

Forward walking

The forward-walking validation report compared Santos predicted normal walking with four healthy adults measured using a Vicon motion-capture system. Determinants included hip, knee, ankle, and pelvic motion. The report describes both qualitative and statistical comparison, and it documents model improvements made after identifying unnatural sharp peaks. [VAL-5]

Ascending stair climbing

The stair-climbing validation compared predicted lower-limb motion with four healthy adults. Hip, knee, and ankle angular displacements were analyzed. The report concludes that Santos was able to simulate motion comparable to normal human motion while also noting differences, the limited subject population, and the need for larger datasets and force-plate information. [VAL-6]

Box lifting

The box-lifting validation compared predicted motion with human lifting data and highlighted an important human-factors issue: different people selected different natural lifting strategies. The validation therefore examined task determinants while recognizing multiple legitimate human strategies. [VAL-7]

VALIDATION LESSON

Human motion is not a single deterministic trajectory. Several reports explicitly identify inter-subject strategy variation as an important source of apparent prediction error. This is a strength of the validation record: variability and discrepancies are documented rather than hidden.

13. 2015 Military-Relevant Validation Campaign

A focused 2015 validation campaign compared Santos with human motion capture on tasks supplied in the Marine Expeditionary Rifle Squad (MERS) context. The reports include both weighted and unweighted conditions and provide task-specific conclusions rather than a blanket “validated” label.

Task	Participants / setup	Key result reported in source	Documented limitations / differences
Vertical jump	5 participants; weighted and unweighted; motion capture	Good correlations/predictions generally reported for lower-body motion; statistical evidence indicated Santos adjusted to added weight in a way not significantly different from subjects. [VAL-8]	Upper-body strategies varied substantially; force profile and some ankle/upper-limb behavior differed.
Jump from box	10 participants; weighted and unweighted; motion capture	Predicted knee and hip angles were relatively close to motion-capture values; weight-condition effects were examined. [VAL-9]	Diverse human jumping strategies contributed to error; ankle, elbow, and shoulder deviations were noted.
Ladder climbing	Human motion capture	Task-specific determinants and predicted motion	Agreement is determinant-dependent; task complexity

Task	Participants / setup	Key result reported in source	Documented limitations / differences
	compared with prediction	compared across ladder climbing. [VAL-10]	and contact sequencing are important.
Stand to prone	5 participants; MERS video/task; weighted and unweighted	Knee, torso, and shoulder flexion were reported as well predicted; added-weight adjustment was statistically similar to subjects. [VAL-11]	Different strategies appeared in ankle, hip, elbow, and shoulder-abduction determinants.
Prone to stand	5 participants; MERS video/task; weighted and unweighted	Change in knees, hips, torso, and shoulder-flexion determinants was reported as well predicted; added-weight adjustment was statistically similar. [VAL-12]	Elbow and shoulder-abduction differences; small number of key frames limited some correlation interpretation.

14. Soldier Task and Equipment-Interaction Evidence

Beyond generic locomotion, the archive contains prediction studies explicitly involving soldier tasks and external equipment. These are highly relevant to SoldierSim because they demonstrate how the underlying research methods were applied to military postures, weapons, carried equipment, and task constraints.

Study	What was modeled	Evidence value
Optimization-Based Prediction of a Soldier's Motion: Stand-Prone-Aim Task	55-DOF full-body digital human; stand-to-prone-to-aim; rifle transfers; collision avoidance; natural point of aim.	The abstract reports realistic predicted motion and close agreement of natural point of aim and other motion determinants with motion-capture data collected at VSR. [MIL-1]
Optimization-based prediction of aiming and kneeling military tasks performed by a soldier	Aiming and kneeling tasks with task and human constraints.	Demonstrates military-specific posture/motion prediction rather than generic locomotion. [MIL-2]
Simulating equipment interaction with predictive dynamics	Human/equipment interaction incorporated into dynamic prediction.	Direct methodological basis for evaluating how external equipment changes human motion. [MIL-3]
Human carrying simulation with symmetric and asymmetric loads	Predicted carrying under different load distributions.	Relevant to packs, asymmetric soldier loads, and equipment configuration. [MIL-4]
Digital human modeling for optimal body armor design	Armor as a design/evaluation problem linked to digital-human response.	Relevant to SoldierSim armor and PPE trade-study workflows. [ARM-1]

Current SoldierSim design direction: guided workflows and decision-oriented outputs built on the underlying Santos science.

15. Validation and Scientific Development Journey

Period	Scientific / validation milestone	Representative evidence
2003-2006	Foundational digital-human modeling: reachability, posture prediction, optimization, predictive dynamics, physiology, hand/grasping, clothing, vision.	Theses/dissertations by Yang, Farrell, Horn, Kim, Marler, Mathai, Potratz, Pitarch; early SAE/ASME papers.
2007-2009	Formal validation methodology emerges while dynamic prediction expands to walking, running, lifting, stairs, ZMP/stability, and biomechanics.	Marler validation methodology; Rahmatalla locomotion protocol; lower-body posture and biomechanics validation; predictive-dynamics papers.
2009-2013	Predictive Dynamics matures as a peer-reviewed method; multi-objective validation, strength surfaces, ladder, soldier tasks, jump, and Hybrid Predictive Dynamics expand scope.	Xiang et al. Predictive Dynamics; Yang et al. MOO posture validation; Frey-Law 3D strength surfaces; stand-prone-aim; ladder and jump studies.
2014-2018	Application breadth grows into PPE, survivability, body armor, internal anatomy, and task-focused military validation.	Armor optimization; survivability reports; MERS task-validation reports; internal-organ modeling.
2019-2026	Continued development of strength/fatigue and soldier performance modeling, with the research base transitioning into commercial productization.	Head/neck reports, fatigue archive, 2022 soldier-task modeling, current SoldierSim/Santos product development.

16. Evidence Matrix by SoldierSim Capability

SoldierSim capability	Scientific foundation	Direct validation / supporting evidence	Evidence status
Warrior configuration / anthropometry	Posture prediction; anthropometry; kinematics; theses and DHM	Posture-validation methodology and multi-objective posture validation.	Strong scientific basis; direct validation for selected posture

SoldierSim capability	Scientific foundation	Direct validation / supporting evidence	Evidence status
	research.		problems.
Dynamic task prediction	Predictive Dynamics / Hybrid Predictive Dynamics.	Walking, stairs, lifting, jumping, ladder, stand/prone validation and military task studies.	Strong, task-dependent direct validation.
Joint torques / biomechanics	Dynamics equations, inverse dynamics, biomechanical modeling.	Santos biomechanics validation; force/trajectory comparisons in locomotion studies.	Strong scientific basis with component/task validation.
Ground reaction forces	Dynamic contact models and task prediction.	Walking/jump validation reports include force comparisons or discuss force-profile agreement.	Validated for selected tasks; task-specific limitations documented.
Strength / capacity	3D strength surfaces, musculoskeletal models.	Experimental strength-surface data; fatigue model validation.	Strong component evidence.
Fatigue	Joint-based fatigue modeling and exertion research.	Fatigue thesis/model validation against empirical endurance/decline data.	Component validation.
Load carriage / load distribution	Carrying and asymmetric-load simulation; stability/ZMP.	Task studies and load-related validation; application evidence.	Strong scientific/application evidence; direct validation varies by task.
Spine shear/compression	Biomechanics and load modeling.	Biomechanical validation framework and task studies.	Scientific/component evidence; specific output validation should be cited by use case.
Vision / eye relief	Vision-performance measures and visibility constraints.	Published vision-performance studies.	Scientific-method evidence; task-specific validation varies.
Armor / PPE	Armor optimization, survivability, task-based PPE studies.	Funded reports and application publications.	Strong application evidence; not equivalent to universal armor validation.
Physiology / thermal / hydration	Physiology, thermal, critical power, energy, substrate models.	Scientific models and reports; validation depth differs by submodel.	Model-based evidence; claims should identify source/model.
Equipment interaction	Predictive dynamics with external equipment, collision constraints, load/carrying studies.	Military task prediction and equipment-interaction publications.	Strong methodological/application evidence.
Behavior / strategy variation	Performance functions, Predictive Dynamics, behavior-induction methods.	Santos behavior papers describe generating different task strategies by changing performance-function priorities.	Scientific-method/application evidence; behavior remains scenario- and formulation-dependent.
Equipment/clothing interaction	Cloth mechanics, contact, soft-tissue and armor-system modeling.	Clothing/armor framework couples fabric mechanics, collision/contact, and human motion to quantify resistance to movement.	Strong scientific/application evidence; implementation scope in current SoldierSim should be stated specifically.
Subject-specific mass & inertia	Avatar geometry segmentation, mass/COM/inertia estimation.	SAE work describes computing segment-specific mass, center of mass and inertia from digital-human geometry.	Strong scientific-method evidence supporting physics-based individualized avatars.
Reach / workspace / layout	Workspace boundary analysis, reach envelopes, zone differentiation.	Published Santos workspace methods consider joint limits and percentile-dependent upper-extremity reach.	Strong scientific-method/application evidence.
Whole-body vibration	Experimental vibration response, discomfort and biomechanical modeling.	Dedicated vibration research includes frameworks and experimental studies of seated/supine whole-body vibration.	Substantial scientific/application evidence; direct use in SoldierSim depends on enabled product modules.
Injury prediction	Predictive Dynamics joint loading combined with detailed injury models.	Published injury work extends predicted joint torque histories toward musculoskeletal injury assessment.	Scientific-method/application evidence; injury outputs should be separately qualified and validated for specific use cases.
Posture / inverse kinematics	Multi-objective posture prediction and optimization-based IK.	A 12-subject, four-task motion-capture validation reported R-square	Direct component validation for selected upper-body posture

SoldierSim capability	Scientific foundation	Direct validation / supporting evidence	Evidence status
		coefficients above 0.70 across within- and cross-percentile comparisons.	problems.
Dual-arm / joint constraint loads	Tree-structured dynamics, optimization and fictitious-joint constraint-load formulation.	SAE peer-reviewed work reports realistic dual-arm motion, actuator torques, and a method for joint constraint forces/moments without numerical integration.	Strong scientific-method evidence for upper-body dynamics and joint loading.

17. Scientifically Defensible Claims and Appropriate Limitations

Claims well supported by the supplied archive

- SoldierSim is built on a multi-decade scientific program in digital human modeling and predictive human motion.
- The Predictive Dynamics methodology has been described in peer-reviewed scientific publications and applied to a wide range of human tasks.
- Santos has been subjected to formal validation methodology development and direct comparisons with human motion-capture data.
- Direct task validation has been performed for walking, stair climbing, lifting, jumping, ladder climbing, stand-to-prone, and prone-to-stand, among other studies represented in the archive.
- The scientific program includes experimentally grounded strength, fatigue, biomechanics, stability, vision, physiology, grasping, PPE, armor, and survivability research.
- Military-relevant studies include aiming, kneeling, stand-prone-aim, equipment interaction, load carrying, armor design, and soldier physical-performance modeling.

Claims that should be qualified

- Avoid stating that "SoldierSim is fully validated" without identifying the capability/task. Validation is task-, metric-, population-, and condition-specific.
- Avoid implying that every output has the same level of direct experimental validation. Some outputs are based on validated submodels or published scientific relationships rather than direct end-to-end validation.
- Acknowledge that human movement strategy varies between people. Several validation reports explicitly identify strategy variability as a source of disagreement.
- When using a model outside the conditions represented in the validation archive, describe results as predictive engineering estimates and identify relevant assumptions.
- For procurement or safety-critical decisions, use SoldierSim as one element of an engineering evidence package rather than a substitute for all physical testing.

RECOMMENDED CUSTOMER WORDING

"SoldierSim is built on the Santos human digital twin and a multi-decade body of peer-reviewed research, formal validation methodology, human motion-capture comparison, component-level model validation, and military application studies. Validation is documented by capability and task; individual analyses should be interpreted within the assumptions and conditions of the supporting evidence."

18. Selected Theses and Dissertations

The supplied archive includes a substantial graduate-research lineage. The following examples illustrate the depth of foundational work feeding the Santos/SoldierSim technology base.

Topic / supplied document	Contribution
Swept Volumes and Reachability - Yang (2003)	Reachability and swept-volume foundations for human/product interaction.
Posture Prediction - Farrell (2005)	Optimization-based posture prediction.
Predictive Dynamics 2 - Horn (2005)	Early Predictive Dynamics formulation and development.
Multi-objective optimization - Marler (2005)	Multi-objective optimization methods supporting human prediction.
Physiology - Mathai (2005)	Physiological-model development.
Muscle force and activation - Patrick (2005)	Muscle force and activation research.
Hand Mechanism - Potratz (2005)	Human hand mechanism development.
Predictive Dynamics - Kim (2006)	Dynamic human motion prediction.
Clothing - Man (2006)	Digital clothing / human-equipment representation.
Grasping - Pitarch (2007 PhD)	Virtual human grasping and object interaction.
A study of optimization-based predictive dynamics... - Hariri	Advanced optimization-based Predictive Dynamics / ZMP research.
Optimization-based dynamic human... - Xiang PhD	Advanced optimization-based human motion prediction.
Modeling and validating joint based muscle fatigue... - Looft	Fatigue-model development and validation.

19. Selected Scientific and Validation References

Reference codes used in this document correspond to representative source files supplied by iHuman. This is a selected evidence list, not the complete publication bibliography.

Code	Selected reference
PD-1	Xiang, Y., Chung, H.-J., Kim, J.H., Bhatt, R., Rahmatalla, S., Yang, J., Marler, T., Arora, J.S., Abdel-Malek, K. "Predictive dynamics: an optimization-based novel approach for human motion simulation." Structural and Multidisciplinary Optimization, 2010.
PD-2	"Hybrid predictive dynamics - a new approach to simulate human motion." Supplied peer-reviewed publication.
PD-3	"Optimization-based dynamic human walking prediction." Supplied publication.
PD-4	"Predictive simulation of human ladder climbing." Supplied ASME publication.
BIO-1	"Validation of Santos biomechanics." Supplied biomechanics publication.
STR-1	Frey-Law, L.A., Laake, A., Avin, K.G., Heitsman, J., Marler, T., Abdel-Malek, K. "Knee and Elbow 3D Strength Surfaces: Peak Torque-Angle-Velocity Relationships." Journal of Applied Biomechanics, 2012.
STR-2	Looft, J.M. "Modeling and validating joint based muscle fatigue due to isometric static and intermittent tasks." University of Iowa thesis, 2012.
STR-3	"A musculoskeletal model of the upper limb." Supplied publication.
STR-4	"ONR Head and Neck Final Report" and "Head-Neck Strength update." Supplied reports.
STR-5	"Relationships between Maximum Holding Time and Ratings of Pain and Exertion Differ for Static and Dynamic Tasks." Supplied publication.
STAB-1	"Efficient ZMP formulation and effective whole-body motion generation for a human-like mechanism." Supplied publication.
STAB-2	"Human carrying simulation with symmetric and asymmetric loads using optimization." Supplied publication.
STAB-3	"Optimization-based dynamic 3D human running prediction - effects of foot location and orientation." Supplied publication.
HAND-1	"Human grasp prediction and analysis." Supplied publication.
HAND-2	"Virtual human hand - autonomous grasping strategy." Supplied publication.
VIS-1	Marler, T., Farrell, K., Kim, J., Rahmatalla, S., Abdel-Malek, K. "Vision Performance Measures for Optimization-Based Posture Prediction." SAE Technical Paper 2006-01-2334.
ARM-1	"Digital human modeling for optimal body armor design." Supplied publication.

Code	Selected reference
ARM-2	“Digital human modeling capabilities for task-based survivability.” Supplied publication.
ARM-3	“Digital Human Model Internal Organs”; “Simulating internal Viscera”; “Dynamic motion of internal anatomy Digital Human Model SURVIVABILITY.” Supplied publications/reports.
ARM-4	“DSTL Hit Detection.” Supplied technical document.
ARM-5	STTR N00014-11-M-0287 Final Report and STTR N00014-13-C-0161 Final Report.
VAL-1	Marler, T., Yang, J., Rahmatalla, S., Abdel-Malek, K., Harrison, C. “Validation Methodology Development for Predicted Posture.” SAE 2007-01-2467.
VAL-2	Rahmatalla, S., Xiang, Y., Smith, R., Li, J., Meusch, J., Bhatt, R., Swan, C., Arora, J.S., Abdel-Malek, K. “A Validation Protocol for Predictive Human Locomotion.” SAE 08DHM-0024 / 2008-01-1855.
VAL-3	Rahmatalla et al. “Validation of lower-body posture prediction.” Supplied publication.
VAL-4	Rahmatalla et al. “Validation of Santos biomechanics.” Supplied publication.
VAL-5	Rahmatalla, S., Smith, R., Meusch, J., Li, J. “Validation of the Predicted Forwards Walking of the Virtual Human Model Santos.” VSR validation report.
VAL-6	Rahmatalla, S., Meusch, J., Smith, R., Li, J. “Lower-Limb Stair Climbing Validation of the Virtual Human Santos.” VSR validation report.
VAL-7	Rahmatalla, S., Li, J., Smith, R., Meusch, J. “Validation of the Box Lifting of the Virtual Human Model Santos.” VSR validation report.
VAL-8	Rahmatalla, S., Ewart, S., Michael, J., DeShaw, J. “Validation of Vertical Jumping for the Virtual Human Model Santos.” 2015.
VAL-9	Ewart, S., DeShaw, J., Michael, J., Rahmatalla, S. “Validation of Jumping from a Box for the Virtual Human Model Santos.” 2015.
VAL-10	“Ladder Climbing 619_2015_Final.” VSR validation report, 2015.
VAL-11	Rahmatalla, S., Ewart, S., Michael, J., Tierney, M. “Validation of Stand to Prone for the Virtual Human Model Santos.” 2015.
VAL-12	Rahmatalla, S., Ewart, S., Michael, J., Tierney, M. “Validation of Prone to Stand for the Virtual Human Model Santos.” 2015.
MIL-1	Hariri, M., Arora, J., Abdel-Malek, K. “Optimization-Based Prediction of a Soldier’s Motion: Stand-Prone-Aim Task.” New Trends in Mechanism and Machine Science, 2013.
MIL-2	“Optimization-based prediction of aiming and kneeling military tasks performed by a soldier.” Supplied publication.
MIL-3	“Simulating equipment interaction with predictive dynamics.” Supplied publication.
MIL-4	“Human carrying simulation with symmetric and asymmetric loads.” Supplied publication.

20. Source Archive Summary

The research archive supplied for this edition included the following collections. The complete file-level inventory can be maintained separately as a controlled bibliography and linked to this document in future revisions.

Collection	Files
HPD to send	11
Biomechanics modeling	13
Hand modeling and Grasping	16
Human Load stability balance	17
Human Performance - Dynamics-Physics based	29
Predictive Dynamics	63
Strength - Fatigue - Muscles	12
Survivability-PPE-Armor	9
Thermal	6
Thesis and Dissertations	18
Validation	16
Vision	5
Behavior	2
Cloth Modeling - soft tissue	15

Collection	Files
Human Factors and Ergonomics	22
Human mass and inertia estimation	2
Human modeling Overview	13
Human Motion and path planning	25
Human Vibration	11
Injury Prediction	7
Physiology	4
Posture - IK	9
Workspace analysis	15
Dual-arm dynamics paper	1

Recommended next evidence-management step

- Create a master bibliography with DOI, journal/conference, year, authors, and publication type for every unique reference.
- Tag every publication to one or more SoldierSim capabilities and identify whether it provides direct validation, component validation, scientific-method evidence, or application evidence.
- For every major SoldierSim output, maintain a one-page “evidence card” listing equations/models used, calibration data, validation studies, known limitations, and software version.
- Add newer validation and customer studies as they become available so the document becomes a living evidence dossier rather than a static marketing brochure.

DOCUMENT STATUS
Expanded consolidated edition based on 24 supplied research collections/items in August 2026. The evidence base now includes behavior, cloth/soft-tissue modeling, human factors and ergonomics, subject-specific mass/inertia, human-modeling overviews, motion/path planning, whole-body vibration, injury prediction, physiology, posture/inverse kinematics, workspace analysis, and the SAE dual-arm dynamics/joint-constraint-load paper, in addition to the original 12 research archives.

21. Expanded Scientific Evidence Added in August 2026

The second evidence submission materially broadens the scientific record supporting Santos and SoldierSim. The added material extends beyond motion prediction into behavior generation, clothing and armor interaction, ergonomics, individualized mass properties, whole-body vibration, injury prediction, physiology, posture validation, workspace/reach analysis, and additional dynamics formulations. These materials strengthen the case that SoldierSim is the commercial application layer of a much broader, long-running human digital twin research program.

21.1 Behavior and strategy generation

The Behavior collection addresses a limitation of deterministic simulation: a real person may use different strategies to accomplish the same task. The supplied Santos behavior paper describes a physics-based framework in which human-performance functions such as energy, vision, reach, and comfort can be used within optimization to induce different behaviors while respecting motion and strength constraints. This evidence is particularly relevant to future SoldierSim analyses in which equipment, anthropometry, fatigue, terrain, or task goals may cause different plausible movement strategies rather than one repeated trajectory.

- Santos the Virtual Soldier Predicts Human Behavior
- Inducing Behavior Summary

21.2 Clothing, soft tissue, and armor interaction

The new clothing/soft-tissue collection adds a substantial body of work on the physical interaction between the human body and clothing, uniforms, and armor. A representative SPIE paper proposes a coupled framework consisting of fabric mechanics/dynamics, collision/contact correction, and a human-motion module, with the objective of quantifying how uniforms or body-armor systems resist movement during physical tasks. This provides scientific context for SoldierSim use cases involving armor bulk, mobility restriction, equipment contact, and protective-system trade studies.

- A clothing modeling framework for uniform and armor system design
- Dynamic cloth simulation
- Functional Clothing
- Towards implementing a real-time deformable human muscle model in digital human environments

21.3 Human factors, ergonomics, and task-based design

The Human Factors and Ergonomics collection demonstrates that the Santos research program has long been used not only to simulate people, but also to improve products and workspaces. Representative studies address vehicle interior layout, reach barriers, lifting, discomfort, zone differentiation, ingress/egress, medical-device evaluation, grasping, and optimization-based placement of controls. One task-based vehicle-layout study explicitly describes using Santos to explore defense-vehicle interiors without first building physical prototypes, while accounting for task-specific motion and joint loading. This body of evidence reinforces SoldierSim positioning as an engineering decision-support tool rather than an animation system.

- Task-based Vehicle Interior Layout Design Using Optimization Method to Enhance Safety
- Human Factors and Ergonomics Tools in Santos
- Human reach envelope and zone differentiation for ergonomic design
- 3D human lifting motion prediction with different performance measures

21.4 Subject-specific mass, center of mass, and inertia

Physics-based prediction depends on physically meaningful body-segment properties. The added SAE paper on mass and inertia estimation describes an integrated method to compute subject-specific segment mass, center of mass, and inertia tensor from digital-human geometry after anthropometric changes. This is important evidence for individualized dynamic simulation because changing avatar dimensions changes the kinematic and dynamic properties of the model. The companion body-surface-area work further demonstrates quantitative use of individualized 3D human geometry.

- Estimation of Mass and Inertia Properties of Human Body Segments for Physics-based Human Modeling and Simulation Applications
- A quantitative assessment of variations in the palm surface area as a percentage of total body surface area within the general population

21.5 Human-modeling architecture and integration

The Human Modeling Overview collection contains multiple papers describing Santos as an integrated or physics-based digital-human environment. These sources are important for explaining the architecture underlying SoldierSim: high-degree-of-freedom human representation, biomechanics, optimization, posture/motion prediction, human factors, physiology, and analysis modules developed as a coordinated research platform rather than isolated algorithms.

- Santos - a digital human in the making
- Santos - a new generation of virtual humans
- Santos - a physics-based digital human simulation environment

21.6 Motion planning, path planning, obstacle avoidance, and control

The added motion/path-planning collection expands the prediction evidence into obstacle avoidance, asymmetrical gait, sensitivity analysis, model predictive control, inverse dynamics, walking formulation, and large-scale optimization. A representative SAE paper on Model Predictive Control uses Santos to produce physically consistent arm-motion simulations in a dynamic virtual environment and specifically addresses response to disturbances not known in advance. This research supports the broader scientific premise that a digital human should respond to changing task and environmental conditions rather than merely replay a prerecorded motion.

- Model Predictive Control for Human Motion Simulation
- Obstacle Avoidance for Motion Simulation
- Motion prediction and inverse dynamics
- Optimization-based Prediction of Asymmetric Human Gait

21.7 Whole-body vibration

The Human Vibration collection provides a distinct experimental and modeling research stream on whole-body vibration, including seated and supine response, discomfort measures, and biomechanical response. A 2007 SAE paper presents a framework for studying human response to whole-body vibration and includes University of Iowa and Caterpillar collaborators. This evidence is directly relevant to vehicle-crew and platform-vibration opportunities, while any SoldierSim claim should distinguish the existence of this research base from the specific vibration functionality implemented in the commercial release.

- A Framework to Study Human Response to Whole Body Vibration
- Whole body vibration in supine humans
- A Quasi-static Discomfort Measure in Whole-body Vibration

21.8 Musculoskeletal injury prediction

The Injury Prediction collection extends the digital-human framework toward injury-risk assessment. A representative paper describes combining Predictive Dynamics joint torque histories with a detailed finite-element model of the same joint to assess propensity for musculoskeletal injury. Other supplied studies address repetitive loading and ankle-joint injury prediction. This is important evidence of scientific extensibility, although injury prediction should be treated as a separately qualified capability and not assumed to be validated for every SoldierSim task or output.

- Digital human method and simulation for predicting musculoskeletal injuries
- Human simulation system for injury assessment due to repetitive loading
- Repetitive-task ankle joint injury assessment using artificial neural network

21.9 Physiology and female extended load carriage

The added Physiology collection provides especially relevant evidence for SoldierSim extended load carriage. A University of Iowa study recruited healthy female college-age subjects for treadmill foot marches from 5 km to 20 km while carrying a 75-lb load and monitored physiological indicators. The reported results included oxygen-consumption differences, respiratory exchange ratio, heart-rate drift, urine specific gravity, core temperature, heart-rate variability, and neurocognitive measures; the study states that results were modeled and entered into Santos to augment the Sophia female model. This strengthens the experimental foundation for sex-specific and extended-duration human-performance modeling.

- Modeling and simulation of backpack load carriage by female subjects for extended durations
- Female Load Carriage Report
- Physiology - Mathai

21.10 Posture prediction and inverse kinematics validation

The Posture/IK collection adds direct validation evidence for optimization-based posture prediction. A Robotica paper reports a multi-objective optimization method validated with twelve subjects divided by percentile across four realistic in-vehicle reaching tasks. Motion capture was used to record wrist, elbow, shoulder, and elbow-angle data; the paper reports coefficients of determination above 0.70 for both within-percentile and cross-percentile comparisons. This is useful direct component-level validation for posture prediction and supports the broader use of human-performance measures as optimization objectives.

- Multi-objective optimization-based method for kinematic posture prediction: development and validation
- Advanced IK

- Posture Prediction
- Discomfort performance

21.11 Workspace, reachability, and zone differentiation

The Workspace Analysis collection documents a broad program in reach-envelope and workspace mathematics, including Santos upper-extremity workspace, boundary surfaces, zone differentiation, placement, swept volumes, and layout design. A representative Computers & Industrial Engineering paper presents a general analytic method for percentile-specific Santos upper-extremity workspace that explicitly considers joint limits and supports real-time visualization of reach envelopes. This evidence is directly relevant to reach, control placement, weapon/equipment access, vehicle packaging, and human-system integration.

- A general analytic approach for Santos upper extremity workspace
- Workspace analysis and visualization for Santos upper extremity
- Workspace zone differentiation and visualization for virtual humans
- Swept Volumes and Reachability

21.12 Dual-arm dynamics and joint constraint loads

The separately supplied 2007 SAE technical paper, “Dual-Arm Dynamic Motion Simulation and Prediction of Joint Constraint Loads Using Optimization,” extends optimization-based dynamics from a serial upper-body chain to a tree-structured torso and two-arm Santos model under external loads. The paper reports realistic dual-arm motions and required actuator torques, and introduces a method to calculate joint constraint forces and moments using fictitious joints and zero-displacement constraints. The formulation provides additional scientific evidence for upper-body task prediction, external-load response, and joint-load calculation in physics-based human simulation.

- Dual-Arm Dynamic Motion Simulation and Prediction of Joint Constraint Loads Using Optimization (SAE 2007-01-2491)

21.13 Effect on the SoldierSim evidence position

Added evidence domain	What it strengthens	Recommended interpretation
Behavior	Ability to represent alternative human strategies and performance-driven motion.	Scientific-method evidence; not a claim that all human behavioral variability is captured.
Clothing / armor mechanics	Human-equipment contact, restriction, and protective-system interaction.	Strong relevance to armor/PPE trade studies; current product implementation should be stated precisely.
Mass / inertia	Subject-specific physics when anthropometry changes.	Foundational dynamic-model evidence.
Human factors / workspace	Reach, layout, product placement, task design and HSI.	Strong application and method evidence.
Vibration	Vehicle/platform human-response research.	Important research lineage; commercial functionality must be identified separately.
Injury prediction	Extension of predicted joint loads toward MSK injury assessment.	Promising scientific extension; use qualified claims.
Physiology	Experimental extended-load-carriage response, including female subjects.	Strengthens human-performance and load-carriage evidence.
Posture / IK	Motion-capture validation across percentile groups and realistic tasks.	Direct component validation.
Dual-arm dynamics	Tree-structured motion prediction and joint constraint loads under external loading.	Strong scientific-method evidence for upper-body dynamics.

22. Additional Selected References from the Expanded Archive

Code	Additional selected reference
BEH-1	Abdel-Malek, K., Bhatt, R., Kregel, K., Murphy, C., Rummells, J.,

	Tenasalais, M., Lichtenstein, K., and Klopfenstein, T. “Santos the Virtual Soldier Predicts Human Behavior.” Supplied paper.
CLOTH-1	Man, X., Swan, C.C., and Rahmatalla, S. “A clothing modeling framework for uniform and armor system design.” Proc. SPIE 6228, 2006.
HF-1	Kim, J., Yang, J., Abdel-Malek, K., and Nebel, K. “Task-based Vehicle Interior Layout Design Using Optimization Method to Enhance Safety.” Supplied paper.
MASS-1	Penmatsa, R., Bhatt, R., Farrell, K., Rochambeau, B., Fruehan, C., Verma, U., Beck, S., and Abdel-Malek, K. “Estimation of Mass and Inertia Properties of Human Body Segments for Physics-based Human Modeling and Simulation Applications.” SAE 2009-01-2301.
MPC-1	Goussous, F., Bhatt, R., Dasgupta, S., and Abdel-Malek, K. “Model Predictive Control for Human Motion Simulation.” SAE 2009-01-2306.
VIB-1	Rahmatalla, S., Xia, T., Ankrum, J., Wilder, D., Frey Law, L., Abdel-Malek, K., Contratto, M., and Kopp, G. “A Framework to Study Human Response to Whole Body Vibration.” SAE 2007-01-2474.
INJ-1	Abdel-Malek, K., Arora, J., Bhatt, R., Sultan, S., Farrell, K., Evans, L., Kregel, K., and Marler, T. “Digital human method and simulation for predicting musculoskeletal injuries.” Supplied paper.
PHYS-1	Bhatt, R., Arora, J., Abdel-Malek, K., et al. “Modeling and simulation of backpack load carriage by female subjects for extended durations (extended load carriage).” Supplied paper.
POST-1	Yang, J., Marler, T., and Rahmatalla, S. “Multi-objective optimization-based method for kinematic posture prediction: development and validation.” Robotica 29 (2011): 245-253.
WORK-1	Yang, J., Sinokrot, T., and Abdel-Malek, K. “A general analytic approach for Santos upper extremity workspace.” Computers & Industrial Engineering 54 (2008): 242-258.
DYN-1	Kim, J.H., Abdel-Malek, K., Yang, J., and Nebel, K.J. “Dual-Arm Dynamic Motion Simulation and Prediction of Joint Constraint Loads Using Optimization.” SAE 2007-01-2491.

23. Revised Source Archive Summary

Across the original and expanded submissions, this edition reviewed 341 supplied files across 24 collections/items. After duplicate base filenames and alternate copies are removed, the supplied corpus represents 272 unique base filenames. These counts describe the materials supplied for review; they are not equivalent to a count of unique peer-reviewed publications because the corpus also contains theses, dissertations, reports, presentations, duplicate versions, and working documents.

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