Application of Exoskeletons for Safe Patient Handling—A Feasibility Study

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Burden: Work-related Musculoskeletal Disorders (MSDs)

- **MSDs are prevalent and costly**
  - 344,970 cases in 2017
  - >30% of all work-related injury and illness cases
  - Total costs: $45 to $54 billion annually
  - Require 44% more time away from work

- **Back injuries are prominent**
  - associated with 37.6% of the MSD cases

- **Overexertion is the most common event leading to MSDs**
  - associated with over 65% of MSD cases

(BLS 2017; OSHA 2000)
Burden: MSDs in Healthcare and Social Assistance (HCSA) Sector

- **MSDs resulting from overexertion during patient handling**
  - Lifting, moving, or repositioning patients
  - Difficult/awkward working postures
  - Unexpected or violent movements of patients or their reactions
  - Inappropriate distribution of the patient load among co-workers

- **Large population of the healthcare workers involving in patient handling:**
  - Registered nurses: 3 million; Home health aides: 0.9 million
  - Nursing assistants/aides: 1.5 million (the second largest healthcare occupation)
  - A special feature of the population:
    - More than 85% are women
    - Lower physical strength

(BLS 2017)
Burden: MSDs in HCSA Sector

- **Healthcare workers have higher MSD rates than other industries:**
  - Average across all industries = 30 cases per 10,000 full-time workers
  - Registered nurses and Home health aides = 44
  - Nursing assistants = 166 (total 18,090 MSD cases; ranked second among all occupations)

- **Costs associated with overexertion injuries in the healthcare industry:** ~$1.7 billion

- **The situation may get worse:**
  - **Rapidly aging population:** ≥ 65 years old may be more than double between 2012 and 2060
  - **Obesity epidemic:** about 42% of the U.S. population is projected to be obese by 2030
  - **Nursing shortage:** estimated up to one million by 2025
  - **Aging healthcare workforce:** nearly half of all nurses will reach the traditional retirement age by 2020
  - **Additional issues with home health aides and personal care aides:**
    - The fastest growing occupations: may add 1.2 million jobs over the 2016-2026
    - Work in an uncontrolled environment (e.g., patient’s home) with limited or no ergonomic assistive equipment

(BLS 2017; NIOSH Science Blog; US Census Bureau)
Current Status

- **The Safe Patient Handling and Mobility (SPHM) programs:**
  - Significant decrease in worker injuries and lost time
  - Investments can be recovered in less than five years
  - Laws requiring SPHM programs
    - Only in 11 of 50 states
    - No federal legislation passed
  - Most influential barriers to implement SPHM
    - Time Constraints
    - Difficult patient-handling situations
  - Unique challenges in uncontrolled or specialized environments (e.g., home healthcare, imaging procedure, ERs)

- Expect continuous progress of the SPHM programs
- Facing severe challenges (latest BLS data and projected burden)
- In great need of improvement and innovative technologies

(ANA 2013; OSHA 2013; Teeple, 2017; Noble, 2018; NORA HCSA Council, 2019)
Ongoing Human-Robot Collaboration Movement in Modern Industry

- **Wearable Robot: Exoskeleton or Exosuit**
  - Augment and enhance worker’s strength, endurance and performance

- **Promising results in the industries involving material handling**
  - 10% - 40% reduction in back muscle activity during dynamic lifting

- **Rapid development and growth**
  - Value of exoskeleton market: $130 million in 2018 → $ 5.2 billion by 2025
  - One of the automobile companies started making a passive exoskeleton mandatory PPE in 2019
  - Lighter, Stronger and Smarter
  - Next-generation robotic PPE: wear comfortably daily with protection against work-related MSDs?

[PPE: Personal Protective Equipment]

(de looze, 2016; Wintergreen Research, 2019)
Japanese Robots in Patient Handling

- Japan: leading nation in robotics with severe aging problems
  - Over a quarter of the population is over 65, and the number will reach 40% of the population by 2065
  - Shortfall of 370,000 caregivers by 2025
Exoskeletons in Patient Handling

- **Scientific and technology gaps:**
  - No commercially available exoskeleton system specifically for patient handling in the US market
  - No standard method for testing and evaluation

- **Major challenges:**
  - Unique “object-handling” task:
    - Irregular and complex “geometry” of lift
    - Consideration of “object”/patient feeling and safety
  - Mostly women users:
    - Women have a significantly higher risk of MSDs
    - Gender differences in anthropometric measurements
  - Special requirements:
    - Spatially-restricted working environment
    - Easy disinfection
    - Noninterference with other medical devices
Objectives: to address knowledge gaps regarding development, assessment and implementation of exoskeletons in safe patient handling

- **To develop a suitable evaluation method**

- **To conduct a feasibility study of exoskeletons for safe patient handling**
  - To be introduced to the uncontrolled or specialized environments
  - To complement to the existing SPHM programs
Specific Aims

1. **Identify** general requirements and potential exoskeletons/prototypes applicable for patient handling, and **pre-test** in an industrial setting

2. Evaluate the efficacy of the screened products in selected **patient handling tasks** using physiological and psychophysical measures

3. Develop **biomechanical models** to quantify the effects of exoskeletons on musculoskeletal loadings

4. Apply an **artificial-intelligence(AI)-guided framework** and approaches to simplify and streamline the exoskeleton evaluation procedure

5. Propose potential **recommendations for the development and implementation** of wearable robots for safe patient handling
Specific Aim 1: Identify and Pretest

- **Available industrial exoskeletons/prototype:**
  - Three passive exoskeletons available in the lab
  - Two powered back-assist exoskeleton/exosuit prototypes
  - Actively searching potential products or prototypes...

- **Pretest: load positioning test**
  - **Setup:** Position and Load Test Apparatus for Exoskeletons (PoLoTAE, NIST) (Bostelman, 2018);
  - **Measures:**
    - kinematics, muscle activations, heart rate, metabolic cost
    - NIST-suggested survey on subject’s feeling and comfort levels
Specific Aim 2: Patient Handling Test

**Subjects:** female healthy nurse assistants from the local hospitals

**“Patient”:** an instrumented human-size dummy (median male size)

**Tasks:** three common tasks in patient handling
1. Turn patient on the side—from both directions
2. Lift patient’s body parts—lower legs with feet
3. Boost patient to head of bed

**Measurements:**

**Kinematics:** whole-body Kinematics of the subject and the dummy

**External forces:** ground reaction force, interaction forces among dummy, subject and exoskeleton

**Physiological measures:** muscle activations (EMG), heart dynamics (ECG), metabolic cost and muscle oxygenation

**Psychophysiological measures:** electrical activity of the brain (EEG) and cerebral oxygenation (fNIRS)

**Subject perceptions:** Rating of Perceived Exertion (RPE) and survey on subject’s feeling and comfort levels
Specific Aim 3: Biomechanical Modeling

- **Predict muscle forces and joint loadings**: cannot be measured directly
- **Two approaches**:
  - EMG-driven forward dynamics approach: input muscle activation (EMG)
  - Inverse dynamics approach: input kinematics and external forces
- **Investigate the assistive and “iatrogenic” effects of exoskeletons**
Specific Aim 4

- Use AI-guided framework to target key measures and parameters for evaluation
- Explore deep learning algorithms to estimate joint kinematics and joint moments/loadings based on videos of human movement

Specific Aim 5

- Key measures and parameters for evaluation will serve as important indicators for product development
- The implementation is expected to adjust accordingly due to possibly drastic advancement in product functions
Suggestions & Comments

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