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A Low-Cost Passive Wearable for Sit-to-Stand Assistance in Low-Resource Contexts: Design and Proof-of-Concept Evaluation

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Abstract– Sit-to-stand (STS) performance is a key indicator of functional mobility and independence in aging populations, yet most assistive solutions remain limited by high cost, bulky designs, powered actuation, or dependence on laboratory-grade evaluation systems. This paper presents a low-cost passive wearable device based on a lateral spring mechanism designed to support knee extension during STS while aiming to minimize potential interference with daily mobility. A proof-of-concept evaluation was conducted using the Five-Times Sit-to-Stand (5TSTS) protocol under two conditions (with and without the device). Kinematic variables (knee angle and hip speed) were extracted from standard video recordings using Kinovea as an accessible motion analysis tool. Results showed reduced 5TSTS completion time for both participants when using the prototype, along with condition-dependent differences in knee angle range and hip speed profiles across cycles. The main contributions of this study include: (a) the development of a mechanically simple and low-cost passive wearable device for sit-to-stand (STS) assistance; (b) the establishment of a reproducible evaluation workflow utilizing the Five Times Sit-to-Stand Test (5TSTS) and video-based kinematic analysis; and (c) preliminary feasibility data indicating that the prototype may affect functional performance and movement dynamics across repeated STS cycles. However, these results should not be considered evidence of efficacy, given the proof-of-concept design and the limited sample size.

Keywords-- sit-to-stand; passive assistive device; wearable device; Kinovea; aging mobility.

I. Introduction

The global population is undergoing a major demographic shift toward aging. By 2050, older adults will comprise about 22% of the world's population, representing one in five people and posing significant challenges for healthcare systems worldwide [1]. This trend increases the need for accessible solutions that support mobility and independence in later life.

One of the most significant health consequences of aging is the progressive decline in mobility, driven by musculoskeletal changes that impair physical function and autonomy [2], [3]. Sarcopenia, characterized by the gradual loss of muscle mass, strength, and function, plays a central role in this decline, with individuals losing an estimated 3% to 8% of muscle mass per decade beginning around age 30 [4]. Osteoarthritis is also prevalent and affects weight-bearing joints such as the hips and knees, causing pain, stiffness, and reduced range of motion [5]. These conditions typically accelerate after age 60, increasing the risk of falls, fractures, and loss of independence.

A widely used indicator of functional mobility in older adults is the sit-to-stand (STS) movement, which involves transitioning from a seated to a standing position without using the arms for support. This task is biomechanically demanding and requires coordinated lower-limb strength, postural control, and neuromuscular precision [6]. Because STS is performed frequently in daily routines, reduced performance directly affects activities of daily living (ADLs), fall risk, and overall quality of life [7].

Over the past decades, research has proposed multiple assistive solutions to address STS limitations. However, many of the most common options rely on external support devices such as walkers, sit-to-stand chairs, or structured aids. While these solutions can improve safety, they often restrict freedom of movement due to bulky designs, reduce usability in confined environments, and may disrupt natural biomechanics by promoting compensatory strategies [8]. In addition, visible assistive devices can negatively impact self-image and contribute to abandonment due to stigma.

Wearable technologies, particularly exoskeletons, have emerged as an alternative by integrating assistance directly into the user's body [9]. Despite promising results and even some commercial developments, most wearable systems remain limited for widespread adoption due to high cost, heavy structures, limited comfort for prolonged use, and dependence on external energy sources. These constraints reduce feasibility for daily use, especially in low-resource settings where affordability and simplicity are essential.

To address these challenges, recent work has shifted toward passive assistive devices that operate without motors, electronics, or batteries, using mechanical elements such as springs and elastic materials to store and redirect energy. However, assessment methods remain inconsistent across studies, and many evaluations rely on expensive motion capture systems, force platforms, or EMG, limiting replicability during early-stage prototyping and in low-resource contexts. In response, this study presents a low-cost passive wearable device based on a lateral spring mechanism designed to assist knee extension during STS while maintaining compatibility with daily mobility. The device is evaluated using the Five-Times Sit-to-Stand (5TSTS) protocol [10], [11] and kinematic measures (knee angle, hip speed, and inter-cycle variability) extracted from standard video recordings analyzed with Kinovea [12], [13], providing an affordable and reproducible validation approach.

II. Background

A. Biomechanics of the Sit-to-Stand (STS) Movement

The sit-to-stand (STS) movement is a biomechanically demanding task that requires coordinated joint motion and muscle activation to raise the body's center of mass from a seated position to upright standing [10], [11]. Because STS involves dynamic changes in momentum and load transfer, it is commonly analyzed in biomechanics research to identify where mechanical demands concentrate and where assistance strategies may provide the greatest functional benefit.

Biomechanical studies commonly describe STS as a sequence of phases characterized by distinct kinematic and kinetic patterns. A frequently adopted framework divides the movement into four phases: (1) flexion momentum, (2) momentum transfer (seat-off), (3) extension, and (4) stabilization.

This phased description is useful for identifying where mechanical demands concentrate and where assistance strategies may provide the greatest functional benefit. Among these phases, the extension phase is often the most physically demanding. During this stage, the user must generate sufficient hip and knee extension torque to overcome gravity and complete the transition to standing, while simultaneously maintaining postural stability. In this work, this phase is explicitly highlighted as critical because it represents the largest portion of the STS movement and is associated with the highest risk of instability.

Because the STS task involves dynamic changes in body momentum and load transfer, effective assistance strategies must consider both performance and safety [14]. Improving STS performance is not only a matter of reducing execution time; it also involves improving movement control, reducing abrupt changes in velocity, and supporting joint coordination patterns [15]. For this reason, biomechanical evaluation is valuable because it captures movement dynamics beyond isolated physiological measures.

Finally, an important requirement for real-world STS assistive devices is that they should not compromise daily mobility. Since users must alternate between standing, walking, and sitting throughout the day, wearable devices must minimize interference with gait and preserve natural range of motion [16]. Therefore, device design and validation should focus on targeted assistance during the extension phase while ensuring that the overall movement remains functional and comfortable for routine use.

B. Kinovea: An Affordable Digital Tool for Biomechanical Analysis

Biomechanical evaluation of STS is commonly performed using laboratory-grade tools such as motion capture systems, force platforms, and electromyography (EMG) [17]. However, these technologies require specialized infrastructure, controlled environments, and significant financial resources, which limits replicability in low-resource settings and during early-stage prototyping.

In response to these constraints, video-based motion analysis tools have gained relevance as accessible alternatives. Kinovea is a free 2D motion analysis software that allows researchers to import standard video recordings and extract kinematic variables such as angles, distances, velocities, and time intervals using calibration and frame-by-frame tracking tools [12], [13]. Its low cost and minimal hardware requirements make it particularly suitable for proof-of-concept validation of wearable assistive devices.

Despite these advantages, Kinovea has methodological limitations [18], [19]. Because it is based on 2D video, it is sensitive to camera placement, calibration quality, and out-of-plane movements. Perspective distortion and tracking errors can affect measurement accuracy, and therefore Kinovea cannot fully replace 3D motion capture systems when detailed multi-planar kinematics are required. These limitations must be acknowledged, particularly when interpreting absolute values rather than relative differences.

Nevertheless, Kinovea is especially appropriate for STS analysis because STS is commonly evaluated in the sagittal plane, where flexion–extension of the hip and knee can be clearly observed [20], [21]. Prior evidence suggests that positioning the camera approximately at 90° relative to the sagittal plane improves accuracy for angular and horizontal measurements. This makes Kinovea a practical and reproducible tool for low-cost biomechanical assessment of STS transitions in early-stage device validation.

III. Materials And Methods

A. Design Approach and Device Concept

This work prioritizes feasibility, affordability, and replicability as key requirements for early-stage development in low-resource contexts. This study followed a user-oriented design approach to develop a low-cost wearable device intended to assist the sit-to-stand (STS) movement [10]. The overall objective was to provide mechanical support for a daily-life task that becomes increasingly difficult with aging, while ensuring feasibility for adoption in low-resource contexts. For this reason, the design was oriented toward mechanical simplicity, low-cost materials, and ease of use, rather than laboratory-optimized solutions that are difficult to replicate outside controlled environments.

Based on the biomechanical characteristics of STS, the device was designed to assist knee extension during the rising phase, which concentrates high mechanical demands and requires coordinated joint torque generation and balance control. The design focus was placed on supporting this phase while minimizing potential restrictions during walking, since a practical assistive solution must remain compatible with gait and routine mobility. To guide development, an iterative prototyping workflow was adopted, structured around the design thinking framework, which emphasizes cycles of defining constraints, generating concepts, building prototypes, and refining them through testing and feedback.

During ideation, multiple concepts were explored and gradually refined into a final solution defined by four main characteristics: lateral placement along the leg, secure anchor points at the mid-thigh and mid-calf, a passive spring mechanism for energy storage and release, and rigid connecting rods for force transmission. The resulting concept was selected because it balances assistance effectiveness with wearability and simplicity. The lateral configuration reduces interference with sagittal-plane motion, while the spring-based mechanism enables passive torque support without motors, electronics, or external power sources.

B. Prototype Development and Materials

The prototype was developed through iterative physical construction, with the goal of producing a functional model suitable for preliminary evaluation under a reproducible protocol. The design was implemented as a fully passive device, meaning that it operates without batteries, sensors, or powered actuation. This decision was aligned with the objective of affordability and long-term usability, as powered systems often increase cost, weight, maintenance requirements, and operational complexity.

Structurally, the prototype consisted of two rigid connecting rods coupled through a compression spring. The mechanical principle of the device is based on elastic energy storage and release: as the user flexes the knee during sitting, the spring compresses and stores energy; during standing, the spring releases energy, supporting knee extension by contributing additional torque. Materials were selected based on accessibility and ease of fabrication, and the final prototype used steel rods, a chrome-vanadium compression spring, wooden bases, Velcro straps, wood glue, and epoxy plasticine. The final design consists of two connecting rods coupled through a compression spring, forming a passive lateral mechanism intended to assist knee extension during STS transitions (Fig. 1).

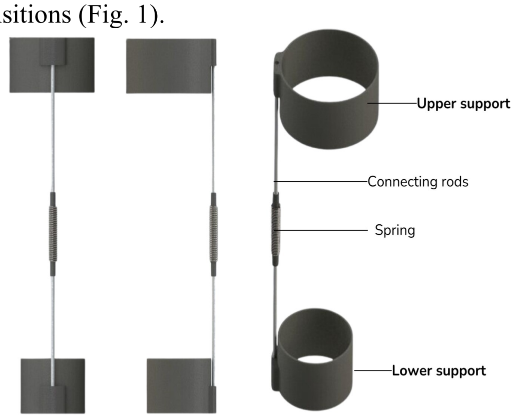

Fig. 1. CAD model of the passive lateral knee-assist device showing the spring-based mechanism and attachment points.

The device design incorporated functional principles relevant to assistive technology, including force distribution through the spring, controlled energy transfer via elastic deformation, and stability through structural rigidity and secure anchoring. Wearability was addressed through Velcro-based fastening, enabling quick donning and doffing. This feature was included because real-world adoption requires that users can apply and remove the device independently, without complex adjustments or external assistance. A functional proof-of-concept prototype was assembled using low-cost materials and Velcro-based fastening to support wearability and ease of donning and doffing (Fig. 2).

Fig. 2. Final prototype iteration of the passive wearable device assembled with low-cost materials and Velcro-based fastening.

C. Participants

A preliminary proof-of-concept evaluation was conducted with two young adults, one female and one male. Both participants were 23 years old, with a reported weight of 70.0 ± 15.6 kg, height of 171.0 ± 11.3 cm, and BMI of 23.6 ± 3.8. Participants were independent in terms of mobility and did not use assistive devices in daily life, and no neurodegenerative conditions were reported that would prevent execution of repeated STS cycles.

One participant presented bursitis at the time of testing, which was documented as part of participant characterization because it could influence movement execution and contribute to variability in outcomes. Given the pilot nature of this study, this factor was retained rather than treated as an exclusion criterion, and results were interpreted cautiously in relation to this limitation.

All participants provided informed consent for video recording and offline analysis, including permission for the use of recordings for research reporting purposes under privacy-preserving conditions. Although the device is intended for older adults, young participants were used at this stage to verify feasibility, confirm device behavior under repeated STS cycles, and validate the proposed low-cost measurement workflow prior to clinical evaluation.

D. Experimental Protocol (5TSTS)

Each participant performed two Five-Times Sit-to-Stand (5TSTS) trials: one without the device and one with the device. The 5TSTS test measures the time required to complete five consecutive sit-to-stand repetitions at maximum speed and is widely used as a functional assessment of lower-limb strength and mobility. Because it captures repeated transitions rather than a single movement, it provides a practical measure of functional performance and consistency. The device was tested on one leg during all trials.

Trials were conducted in a controlled environment to ensure comparable conditions across participants and device states. A straight-backed chair without armrests was used, featuring a firm seat and backrest, and it was placed against a wall to minimize displacement and improve safety during rapid repetitions. Participants were instructed to sit upright in the middle of the chair with both feet fully supported on the floor and to keep their arms raised or positioned at chest level to prevent upper-limb assistance.

Each trial started with a progressive verbal countdown (“1, 2, 3”), which also marked the start of timing. Participants were instructed to complete five repetitions at the highest possible speed while maintaining safe and controlled movement. The test ended after the fifth repetition in a seated position, and all trials were video recorded to enable offline kinematic analysis and comparison between conditions.

E. Video-Based Data Analysis and Outcome Measures (Kinovea)

Kinematic analysis was conducted using Kinovea, a free 2D motion analysis software capable of extracting joint angles and velocity data from standard video recordings. This approach was selected to support a low-cost, reproducible evaluation workflow that does not require laboratory-grade infrastructure, which is especially relevant during early-stage prototyping and in low-resource contexts.

Recorded videos were imported into Kinovea and analyzed frame-by-frame. Tracking was performed to obtain time series data for each repetition, enabling cycle-level extraction of kinematic variables. Knee angle was selected as a primary outcome to quantify joint mechanics and to examine whether the device altered the range of motion during STS transitions. Minimum and maximum knee angles were extracted for each cycle to summarize movement limits across repetitions.

Hip speed was included as a dynamic outcome to characterize movement execution and control. Minimum and maximum hip speeds were extracted per cycle for both sit-to-stand and stand-to-sit phases, and descriptive statistics were computed to examine consistency and variability. Due to the proof-of-concept design and the limited sample size, data analysis was restricted to descriptive comparisons between conditions. Inferential statistical tests were not conducted because formal hypothesis testing would not yield meaningful or generalizable evidence with only two participants. Therefore, the analysis focused on within-participant differences in completion time and descriptive kinematic patterns to evaluate the feasibility of the prototype and the proposed low-cost evaluation workflow.

IV. RESULTS

A. 5TSTS Completion Time

Total completion time for the Five-Times Sit-to-Stand (5TSTS) test was recorded for both participants under two conditions: without the device and with the device. Both participants completed the test faster when using the prototype. The female participant reduced total execution time from 10.37 s to 9.60 s, while the male participant reduced time from 10.58 s to 10.04 s.

B. Knee Angle Across STS Cycles

Knee angle was extracted for each STS repetition to quantify joint kinematics across cycles. Minimum and maximum knee angles were computed for both conditions. Across repetitions, minimum knee angles remained similar between conditions. In contrast, maximum knee angles were consistently lower when the device was used (Table I). Fig. 3 presents the knee angle profiles across the five STS cycles for both conditions. Table I summarizes the mean and SD of minimum and maximum knee angles across cycles for both conditions.

TABLE I
Knee angle range across STS cycles (mean ± SD) with and without the prototype

Condition	**Min mean (°)**	**Min SD**	**Max mean (°)**	**Max SD**
Without prototype	87.134	0.747	166.321	2.313
With prototype	86.629	1.945	158.517	2.678

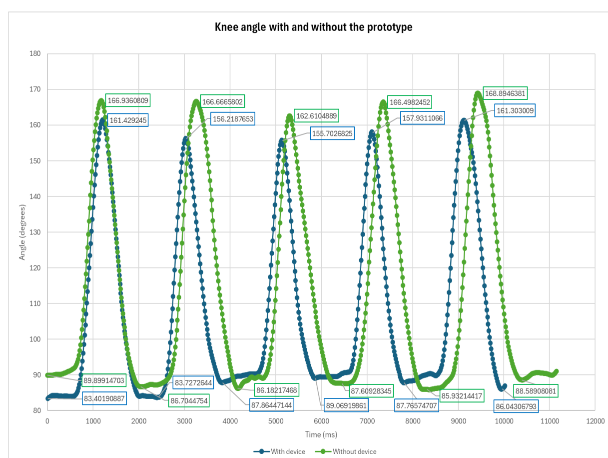

Fig. 3. Knee angle profiles across the five STS cycles with and without the device.

C. Hip Speed and Inter-Cycle Variability

Hip speed was extracted for both sit-to-stand (STS) and stand-to-sit (S2S) transitions to characterize movement dynamics under the two experimental conditions. For each repetition, the hip speed profile was obtained from the Kinovea time series, allowing identification of minimum and maximum speed values and examination of inter-cycle consistency across the five cycles.

As shown in Fig. 4, the device condition produced a consistent hip speed pattern across repetitions. During the STS phase, peak hip speed values tended to be lower when using the prototype compared to the no-device condition. During the S2S phase, the device condition showed less dispersion in peak values and a more homogeneous profile across cycles, showing lower dispersion in peak values across cycles.

To support a descriptive assessment of consistency, variability was examined across repetitions using the shape of the hip speed profiles and the dispersion of peak values across cycles. Overall, the results indicate that the prototype influences hip speed dynamics during both STS and S2S transitions, while maintaining repeatable movement patterns across consecutive repetitions.

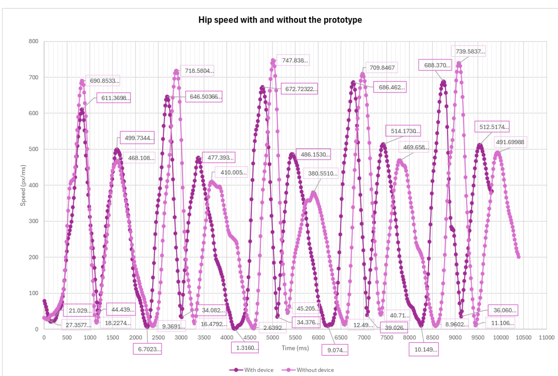

Fig. 4. Hip speed profiles across STS and S2S cycles with and without the device

V. Discussion

The results of this proof-of-concept study suggest that the proposed passive lateral spring mechanism can provide functional assistance during repeated sit-to-stand transitions. The 5TSTS test is widely used as a functional indicator of lower-limb performance and mobility, particularly in older adult populations [11], [15]. Both participants completed the 5TSTS test faster when using the device, indicating that the prototype can influence task performance under controlled conditions. Although the sample size is limited, the consistent time reduction across both participants supports the feasibility of the concept and justifies further refinement and evaluation. Although the prototype was tested on young adults for safety and feasibility, future studies will target older adult populations (≥65 years), which represent the intended user group.

Kinematic results provide additional insight into how the device may influence movement dynamics. Knee angle measurements showed that the device did not introduce large restrictions in the flexion–extension range during STS cycles, suggesting that the mechanism can operate without severely constraining joint motion. The reduction in maximum knee angle observed with the device may reflect a slight mechanical constraint, which should be further evaluated in future iterations. This aligns with classical biomechanical descriptions of STS as a multi-phase task, where the extension phase concentrates the highest mechanical demands [6], [14]. Hip speed profiles showed condition-dependent differences across repetitions, including lower peak speeds during STS when using the device and a more homogeneous pattern across cycles during S2S. These outcomes support the relevance of velocity-based variables for describing STS dynamics beyond task completion time.

From a humanitarian and applied engineering perspective, the proposed approach contributes a replicable pathway for mobility-assistive device development under resource constraints. Unlike powered exoskeletons and laboratory-dependent evaluation pipelines, the prototype relies on passive components and low-cost materials, reducing cost, complexity, and maintenance requirements. In parallel, the use of a video-based kinematic workflow using Kinovea supports accessible evaluation without motion-capture laboratories, force platforms, or specialized infrastructure. This is particularly relevant in Latin America, where assistive technologies are often constrained by limited access to biomechanics laboratories, high device costs, and maintenance barriers that restrict adoption beyond specialized centers.

This study has limitations that must be considered when interpreting results. The evaluation was conducted with two young adults rather than older adults, and therefore the findings cannot be generalized to the target population. This is particularly relevant because STS performance is influenced by biomechanical and neuromuscular control mechanisms that differ between young and older adults, as reported in recent systematic evidence [6]. In addition, kinematic analysis was performed using 2D video, which is sensitive to camera placement, perspective, and out-of-plane movement. Although gait was not evaluated in this proof-of-concept study, the device was designed to maintain compatibility with daily mobility. While Kinovea has shown validity and reliability for obtaining angles and distances under controlled conditions [13], its accuracy can be affected by camera perspective and calibration technique in standard video recordings [19]. Furthermore, this study did not include force platforms or EMG, limiting conclusions regarding joint kinetics and muscular effort. Despite these limitations, the findings provide preliminary evidence that the prototype can influence 5TSTS performance and kinematic patterns, supporting continued development and future testing in larger samples and older adult cohorts. The results should be interpreted strictly as preliminary feasibility evidence given the limited sample size and proof-of-concept nature of the study.

VI. CONCLUSION

This work presented a low-cost passive wearable device designed to assist the sit-to-stand (STS) movement through a lateral spring-based mechanism intended to support knee extension while aiming to minimize potential interference with gait. The proposed design prioritizes mechanical simplicity, affordability, and wearability, addressing practical barriers that commonly limit assistive technology adoption in low-resource contexts.

A preliminary proof-of-concept evaluation employing the Five-Times Sit-to-Stand (5TSTS) protocol showed reduced completion times for both participants when using the prototype. Due to the very limited sample size, these findings should be regarded solely as preliminary evidence of feasibility rather than as evidence of device efficacy. Video-based kinematic analysis using Kinovea facilitated the extraction of knee angle and hip speed profiles from standard recordings, thereby supporting a reproducible and accessible validation workflow appropriate for early-stage prototyping.

Beyond the prototype, the main contribution is an affordable and replicable engineering approach that combines passive assistance with low-cost evaluation. This aligns with humanitarian engineering priorities in Latin America, where solutions must be scalable, maintainable, and testable without specialized labs. The integration of passive assistance and video-based validation supports development and testing in low-resource settings. Future work will focus on improving comfort and adjustability, and expanding testing with older adults using additional biomechanical and clinical measures.

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