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Abstract	Recent studies indicate that back diseases are increasing annually due to various factors such as poor lifestyle habits, aging, pregnancy, and accidents. Patients with such conditions often experience difficulty in managing their backs, leading to a lower quality of life as they endure back pain when sitting for prolonged periods or when transitioning between sitting and standing positions. Sit-to-Stand (STS) movement is particularly challenging for these patients. In response, this study proposes a variable assist chair that supports the user's STS movements. Non-powered assist chairs using the first-class lever mechanism can be advantageous due to their light weight and low cost. Additionally, the chair's variable design enables it to be universally applicable across a wide range of environments and users. This research demonstrates the effectiveness of the new mechanism in assisting users’ transitions between sitting and standing positions. Furthermore, it highlights the need for further research to explore the applicability of the mechanism to a diverse range of users.

Keywords (separated by '-')	Sit-to-Stand Movement - Variable Assist Chair - Ergonomics Analysis - Simulation Exercises

Analysis of Variable Sit-to-Stand Assist Chair

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Abstract. Recent studies indicate that back diseases are increasing annually due to various factors such as poor lifestyle habits, aging, pregnancy, and accidents. Patients with such conditions often experience difficulty in managing their backs, leading to a lower quality of life as they endure back pain when sitting for prolonged periods or when transitioning between sitting and standing positions. Sit-to-Stand (STS) movement is particularly challenging for these patients. In response, this study proposes a variable assist chair that supports the user's STS movements. Non-powered assist chairs using the first-class lever mechanism can be advantageous due to their light weight and low cost. Additionally, the chair's variable design enables it to be universally applicable across a wide range of environments and users. This research demonstrates the effectiveness of the new mechanism in assisting users' transitions between sitting and standing positions. Furthermore, it highlights the need for further research to explore the applicability of the mechanism to a diverse range of users.

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1 Sit-to-Stand Movement

1.1 The Importance of Sit-to-Stand Ability in Daily Living

Due to population growth and aging, the global incidence of low back pain (LBP) is steadily increasing. According to the World Health Organization (WHO), an estimated 619 million people worldwide suffered from LBP in 2020, projected to rise to 843 million by 2050. LBP is the most prevalent musculoskeletal condition and a leading cause of disability worldwide. Moreover, it can result from various factors, including lifestyle habits, pregnancy, accidents, strokes, and Parkinson's disease, affecting individuals across all demographics. Back difficulties can cause pain during prolonged sitting or when transitioning from sitting to standing, significantly impacting quality of life [1]. Sit-to-stand (STS) movement, transitioning from sitting to standing, is crucial for daily activities, particularly for the elderly. Impaired STS function can lead to limitations in daily activities, reduced mobility, and increased mortality risk [2].

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1.2 Phases of STS Movement

Sit-to-stand (STS) movement requires a combination of complex abilities. As the body's center of gravity (COG) shifts, trunk control becomes essential. Additionally, dynamic balance is necessary to prevent falls caused by sudden changes in the base of support and the acceleration of the body's center, ensuring stable limb movements [3]. The ability to place and maintain both feet on the ground and generate extension in the lower limbs is also crucial.

STS process is divided into four phases based on changes in the center of gravity (COG) and hips position. The first phase, flexion-momentum, starts with the initiation of movement and ends just before the hips lift off the chair. The second phase, momentum-transfer, spans from the moment the hips leave the chair until the maximum dorsiflexion (DF) of the ankles. The third phase, extension, follows maximum DF and involves lifting the body vertically until hip extension ends. During phases 2 and 3, the COG shifts from the chair to the feet, presenting the greatest challenge for older adults and individuals with disabilities. Additionally, in phase 3, the trunk must move forward, and the hips must be lifted using the strength of the thigh muscles, but this is hindered by weakness in the spinal erector muscles and quadriceps [1]. The final phase, stabilization, begins after hip extension is complete and ends when all movement ceases [2].

2 Design of Variable STS Assist Chair

Existing assist chairs are often designed for specific patients or the elderly, typically equipped with motors and batteries, making them heavier and more expensive compared to standard chairs. Furthermore, rehabilitation experts caution that motorized lift devices could accelerate muscle degeneration [4]. Studies indicate that elderly individuals and those with limited lumbar mobility tend to struggle with phase 3 of STS, requiring them to grasp their knees or the chair's armrests for support when rising [5]. We used a first-class lever mechanism in the chair to address this dependency on armrests for weight-bearing during STS. As illustrated in Fig. 2, pressing the armrest causes the seat to rise, providing support to the hips and lumbar. The chair can provide users with more flexible support through this variable mechanism. The effort point of the lever, corresponding to the armrest, is set while the chair's bottom frame acts as the fulcrum and the backrest frame as the load point that raises the seat and the backrest. Springs are installed on the armrest and backrest frame to ensure the mechanism returns to its initial state after operation. Based on this design, we made a 1:1 scale prototype using aluminum profiles, as depicted in Fig. 1b.

3 Ergonomic Analysis with Simulation Exercises

3.1 Analysis Method of Variable Assist Chair

The Importance of Ergonomic Analysis. Given that the variable chair is designed to assist STS movements, it necessitates ergonomic analysis for its evaluation. In a study on elderly individuals evaluating a variable assist chair, participants performed Back-to-Sit (BTS) movements after a 3-s pause following Sit-to-Stand (STS) action. The study analyzed knee and pelvis angles [4].

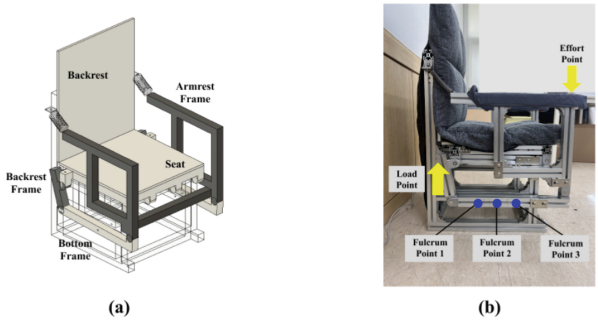

Fig. 1. Design of the Variable STS Assist Chair: **(a)** Modeling of the chair. **(b)** 1:1 scale of prototype chair with aluminum profiles.

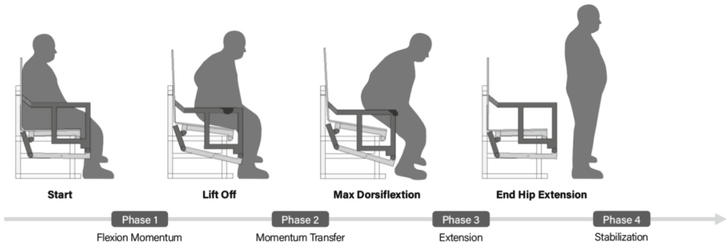

Fig. 2. The chair assists the user according to the stages of STS movement.

Simulation Exercises. In experiments involving the testing of a new chair structure on elderly and disabled individuals, the risk of injury exists, prompting the adoption of simulation exercises [6]. Simulation exercise methodology involves setting up conditions resembling real-life scenarios to facilitate experiential testing, allowing immersion into the actual user experience and incorporating insights into the design [7]. A study utilizing Maternity-Simulation Jackets to prevent potential adverse effects on pregnant women and fetuses, and a study utilizing AGNES (Age Gain Now Empathy System) elderly simulation suits at MIT AGELAB serve as typical examples of simulation exercises [8, 9].

3.2 Experiments

Experimental Protocol. The participants' behaviors were analyzed based on their heights, with cameras positioned 2 m away capturing frontal and side views of their Sit-to-Stand (STS) process. After receiving instructions, participants stood in front of the assist chair and performed STS movements according to cues from the facilitator. The experiment involved random sequences of four chair conditions: a standard chair with no assistance (Without Mechanism), and three variations of fulcrum points—designated as Fulcrum Point 1, 2, and 3, representing the shortest to longest distance from the fulcrum point to the load point, respectively. Participants performed STS under both restricted (wearing a lumbar restraint device) and unrestricted conditions for all chair types, totaling eight trials per participant.

Data Processing. We used Google Teachable Machine to capture and analyze participant movements from the front and side as depicted in Fig. 3. In the STS process, phase 2 (momentum-transfer) begins when the hips lift off the chair seat, and phase 3 (extension) starts when the hands leave the armrests. Pelvic angles and knee angles were measured from the extracted images and summarized in Tables 1 and 2.

Fig. 3. STS Phase 2 of Fulcrum Point 1 to 3 analyzed by Google Teachable Machine: (a) Without Lumbar Restraint Device, (b) With Lumbar Restraint Device

3.3 Results

Wearing the lumbar restraint device on the standard chair without the mechanism generally results in increased angles of the knees and pelvis compared to when there were no restrictions. In both Phase 2 and Phase 3, without the restraint device, the angles of the pelvis and knees tended to increase as the distance from the fulcrum to the effort point decreased, following Fulcrum Points 1, 2, and 3. However, no consistent pattern was observed in the results based on the fulcrum position when the lumbar restraint device was worn.

Table 1. Body Angles of Participants in Experiment without Lumbar Restraint Device

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Without Mechanism	Phase 2	Pelvis	74.1	68.7	63.3	72.5	58.5	80.0
		Knee	108.0	117.0	107.2	100.8	101.6	100.3
	Phase 3	Pelvis	123.9	117.1	136.9	111.8	120.8	134.3
		Knee	141.6	148.2	149.9	142.8	123.8	137.1
Fulcrum Point 1	Phase 2	Pelvis	90.4	51.9	68.4	77.0	67.2	62.3

(*continued*)

Table 1. (*continued*)

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
		Knee	105.0	114.5	104.0	96.9	103.2	101.1
	Phase 3	Pelvis	143.0	121.6	126.5	119.2	82.3	132.3
		Knee	141.8	158.0	159.9	146.2	115.9	143.5
Fulcrum Point 2	Phase 2	Pelvis	65.5	67.3	70.2	77.7	76.4	72.4
		Knee	106.4	121.3	104.2	98.6	104.0	104.8
	Phase 3	Pelvis	121.3	108.6	117.8	122.1	128.7	130.3
		Knee	139.0	158.4	150.8	149.1	137.2	148.4
Fulcrum Point 3	Phase 2	Pelvis	78.2	68.2	66.4	65.6	87.0	73.9
		Knee	111.4	110.7	106.7	97.2	103.7	103.5
	Phase 3	Pelvis	132.5	127.2	111.6	114.8	131.1	122.4
		Knee	148.5	166.2	141.1	140.1	135.2	150.0

Table 2. Body Angles of Participants in Experiment with Lumbar Restraint Device

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Without Mechanism	Phase 2	Pelvis	93.4	68.8	70.4	83.6	87.3	107.4
		Knee	128.9	120.8	116.5	104.4	97.7	166.6
	Phase 3	Pelvis	158.1	121.3	105.5	107.5	142.5	139.3
		Knee	153.2	166.1	153.1	139.6	138.1	169.5
Fulcrum Point 1	Phase 2	Pelvis	93.2	58.0	62.9	70.0	68.7	78.9
		Knee	132.2	86.3	96.9	104.1	97.2	86.4
	Phase 3	Pelvis	140.4	129.2	126.8	105.4	145.3	125.5
		Knee	146.5	167.7	160.6	130.8	137.4	151.6
Fulcrum Point 2	Phase 2	Pelvis	82.3	59.0	81.6	72.4	73.7	74.8
		Knee	110.6	108.6	106.5	97.5	102.3	104.9
	Phase 3	Pelvis	134.2	136.9	123.3	123.9	119.6	112.1
		Knee	148.6	165.6	153.6	140.2	129.3	148.1

(*continued*)

Table 2. (*continued*)

Participant			1	2	3	4	5	6
Height (cm)			149	160	169	172	176	183
Fulcrum Point 3	Phase 2	Pelvis	96.1	54.8	81.9	77.9	84.2	78.7
		Knee	117.4	110.7	109.3	109.8	109.5	109.6
	Phase 3	Pelvis	142.9	130.1	116.8	106.8	147.6	135.6
		Knee	149.4	160.5	145.0	136.9	148.5	151.9

4 Discussion

The participants reported feeling assisted by the chair during STS motion both with and without the lumbar restraint device. However, they felt significantly more comfortable with the restraint device. Measurements indicated that wearing the lumbar restraint device generally increased the angles of the knee and pelvis compared to not wearing the device. This increase in angles is hypothesized to cause greater moments, potentially leading to increased difficulty in movement. The type of fulcrum point that participants found most comfortable differed according to their height. Relatively shorter participants preferred the fulcrum point to be positioned towards the front. Indeed, these participants tended to have reduced knee and pelvis angles in this case. This is because they sit towards the front of the seat, placing their sitting area within the seat's upward motion range.

Analysis of recorded videos and angle results showed that participants' movements were unstable when wearing the lumbar restraint device, indicating discomfort during STS. This highlights the value of using simulation exercises to assess different STS movements. However, since there is a lack of regularity revealed in the movement in an uncomfortable state, additional data collection is necessary. Also, while this study analyzed the knee and pelvis angles during STS movement using motion capture, additional experiments, such as examining COG movement, may be necessary and could require extra sensors like pressure sensors.

If further validation in future studies confirms the widespread adoption of chairs incorporating this new variable mechanism, it is anticipated that not only individuals with disabilities or the elderly but also the general population would benefit from its utilization.

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Chapter 15

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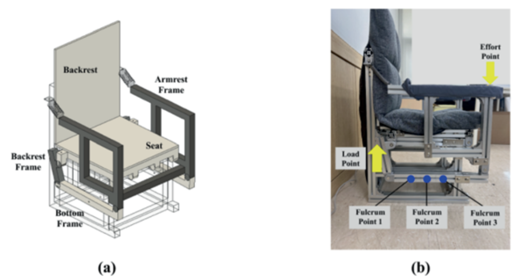
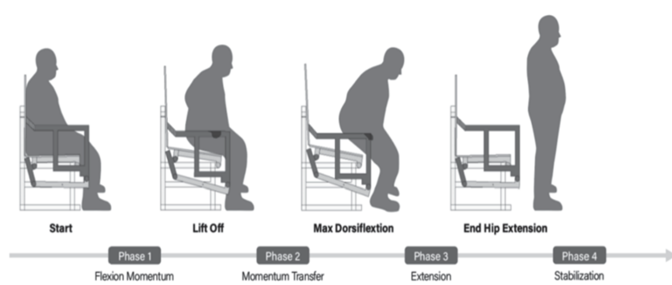
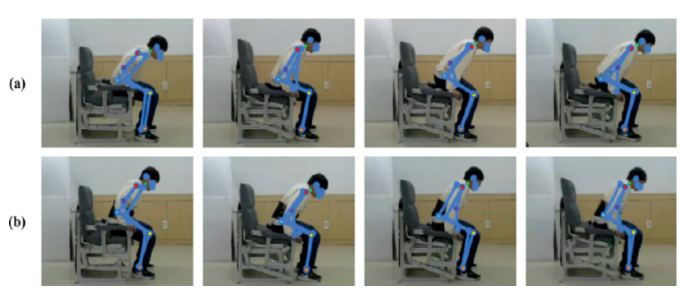
3	Fig1		Diagram of a chair design with two panels. Panel (a) is a sketch showing the chair's structural components labeled as backrest, armrest frame, seat, backrest frame, and bottom frame. Panel (b) is a side view photograph of the chair, highlighting mechanical points with labels: effort point, load point, and fulcrum points 1, 2, and 3. The image illustrates the chair's mechanical design and functionality.
3	Fig2		Diagram illustrating the phases of standing up from a seated position. It shows four silhouettes in sequence: "Start" with a person seated, "Lift Off" as the person begins to rise, "Max Dorsiflexion" with the person leaning forward, and "End Hip Extension" standing upright. Below, phases are labeled: Phase 1 "Flexion Momentum," Phase 2 "Momentum Transfer," Phase 3 "Extension," and Phase 4 "Stabilization." The diagram highlights the biomechanics of transitioning from sitting to standing.
4	Fig3		A series of eight images showing a person performing a sit-to-stand motion from a chair. The images are divided into two rows labeled (a) and (b). Each image captures a different stage of the movement, with overlaid blue lines and red dots indicating joint positions and body posture. The background is a plain room with a chair and a wall. The sequence illustrates the biomechanics of the action.