DE GRUYTER Biomed. Eng.-Biomed. Tech. 2026; 71(3): 163–187

Review

Musfirah Abd Aziz, Nur Azah Hamzaid*, Haidzir Manaf and Noreha Abdul Malik

Arm support as hidden assistance during Sit-To-Stand movement: a systematic review

https://doi.org/10.1515/bmt-2025-0348
Received September 9, 2025; accepted February 10, 2026;
published online February 26, 2026

Abstract: Sit-To-Stand (SitTS) training is often performed by patients who may require arm assistance to perform it successfully. This study examines the role of arms in performing the SitTS maneuver to better understand their contribution and clinical significance. This review synthesizes the reported outcome measures of arm-assisted SitTS exercise programs in people with physical impairments. Web of Science (WoS) and Scopus™ databases were searched for relevant studies up to May 2025. Inclusion and exclusion criteria were used to screen the titles and abstracts of articles identified using key search terms related to SitTS activity and arm support. Only articles that met the key terms were extracted and analyzed in this study. A total of 47 studies reported arm support measures during SitTS, either in clinical or biomechanical contexts. These studies highlighted various methods and tools used to assess the body's state during the rising movement. Joint angle and SitTS duration are clinically applicable and more easily measured compared to seat, foot, and arm forces which require specialized instrumentation. Balancing clinical measures with detailed biomechanical assessments is important in enabling practitioners and researchers to evaluate and enhance SitTS interventions that involve arm assistance, ultimately improving rehabilitation outcomes.

***Corresponding author: Nur Azah Hamzaid**, Centre of Applied Biomechanics, Faculty of Engineering, Universiti Malaya, 50603, Kuala Lumpur, Malaysia, E-mail: azah.hamzaid@um.edu.my. https://orcid.org/0000-0002-4277-2813
Musfirah Abd Aziz, Biomechatronics and Neuroprosthetics Laboratory, Department of Biomedical Engineering, Faculty of Engineering, Universiti Malaya, Kuala Lumpur, Malaysia
Haidzir Manaf, Centre for Physiotherapy Studies, Faculty of Health Sciences, Universiti Teknologi MARA, Puncak Alam Campus, Puncak Alam, Selangor, Malaysia
Noreha Abdul Malik, Department of Electrical and Computer Engineering, Kulliyyah of Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia

Keywords: arm assistance; arms contribution; biomechanics; rehabilitation; Sit-To-Stand

Introduction

Sit-to-stand (SitTS) movement, also known as the chair rise task, is a vital functional activity required for various daily movements, such as getting out of bed, walking, and climbing stairs. It reflects an individual's ability to perform the SitTS task independently using lower extremity strength alone. This daily task is essential for maintaining functional independence, mobility, and overall physical well-being [1]. Although SitTS may appear simple, it can have significant effects on SitTS performance, particularly in individuals with impairment or loss of function, where compensatory strategies need to be considered [2, 3]. Early in rehabilitation, not all patients are able to perform SitTS without arm assistance; hence, their progress cannot be fully evaluated before they can perform SitTS on their own.

Several studies have reported overall movement performance; however, the use of assistive devices involving the arms has only been briefly addressed in their methodologies. Previous review on SitTS exercises have focused primarily on its determinants and improvements in physical capacity measures [1, 4]. The performance of the SitTS movement is significantly affected by the chair seat height, the use of armrests, and foot positioning. Each of these elements plays a critical role in determining the efficiency and safety of the SitTS task, particularly among different populations such as older adults and individuals with musculoskeletal disorders. A recent review highlighted the effectiveness of SitTS exercises in improving balance among patients with various neurological conditions [3].

However, a notable gap exists in the comparative analysis of different assessment methods for the SitTS movement, particularly regarding the role of upper limb (UL) positioning and use during these exercises. This review examined the effect of SitTS exercise programs, involving arm assistance on patient-related outcomes in people with physical impairments due to health conditions.

In the context of this review, arm support refers to any physical assistance provided to or utilized by the UL during the SitTS movement. This may include chairs with armrests, assistive devices such as walkers placed in front of the chair, handrails mounted on a wall beside the seat, or even the use of arm momentum (swinging or thrusting) to generate an upward force that aids in rising from the chair.

Considering that determinants and outcome measure criteria depend on the protocol used and are specific to the population studied, there are no published reviews that specifically focus on the arm assistance contribution. An updated review is warranted to gain insight into studies on the value of arm support on the SitTS movement, especially in view of its role due to the neurological conditions. Therefore, this systematic review analysis aims to (1) gain insight into studies protocol on the related arm support contribution in available SitTS study movement and (2) investigate its role of the ‘hidden assistance’, i.e., arm force parameters and outcome measures, which are under-reported but could be of significant value if better understood.

Methods

Literature search strategy

This systematic review was performed according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [5]. The literature search was carried out from October 2023 to May 2025 through two electronic databases: Scopus and Web of Science. The search terms used are presented in Table 1. All manuscripts were imported to EndNote X8 (Thomson Reuters, Carlsbad, CA) and duplicates were removed.

Eligibility criteria

Studies on arm-assisted SitTS by healthy individuals or with physical impairments due to health conditions published between June 1992 and May 2025 were included in this review. In Stage I, the relevant keywords were required to appear in the title or abstract of the articles to be included. However, keywords that were used in the title or abstract but had a different meaning or were not relevant to the intended scope were excluded. Subsequently, to ensure accurate assessment of study quality, duplicate articles and articles without full text available were also screened and excluded.

Table 1: Search term used in the study.

Search topic	Keywords
Activity	“Sit To Stand” OR “Sit-To-Stand” OR “Standing Up”
Search topic measures	hand* OR arm* OR “upper limb”

In Stage II, studies were excluded if arm support was not the main intervention and consisted only of methodology conditions. Additionally, studies that do not have the full paper, including proceedings papers or meeting abstracts, were excluded too. This was to remove studies that lacked adequate data for accurate assessment of study quality. One study was excluded because the article was retracted by the journal. Studies published in English language and those that met the other eligibility criteria were retained for further analyses.

In Stage III, all included studies were fully read through, and those that met the inclusion criteria, including discussion of arm contribution and its outcome measures were retained.

Results

Characteristics of included studies

Initially, 3,694 articles were retrieved for possible inclusion (Figure 1). After title and abstract screening, 2,405 articles were retained for Stage I review. A total of 153 articles specifically related to arm support in SitTS were included in Stage II review. Finally, for Stage III, 47 studies related to arm support contribution were included for assessment of study quality. Outcome measures also included parameters that may not necessarily represent the main findings of the reviewed studies.

Timeline in the publication of studies related to arm support contribution in SitTS

Figure 2 presents an infographic summarizing 47 studies related to the contribution of arm-assisted SitTS movement, as identified across various databases. This visual timeline offers a clearer understanding of the progression of research over the past 33 years, beginning in June 1992 with foundational studies that primarily explored the biomechanics of SitTS, focusing on the roles of different body segments. In the early stages from 1990s to early 2000s, the majority of studies, such as those by Schultz et al., [6], Naqvi et al., [7], and Bahrami et al., [8], focused on biomechanical aspects. These works primarily established baseline knowledge by validating forces, analyzing joint mechanics, and developing theoretical frameworks within clinical contexts.

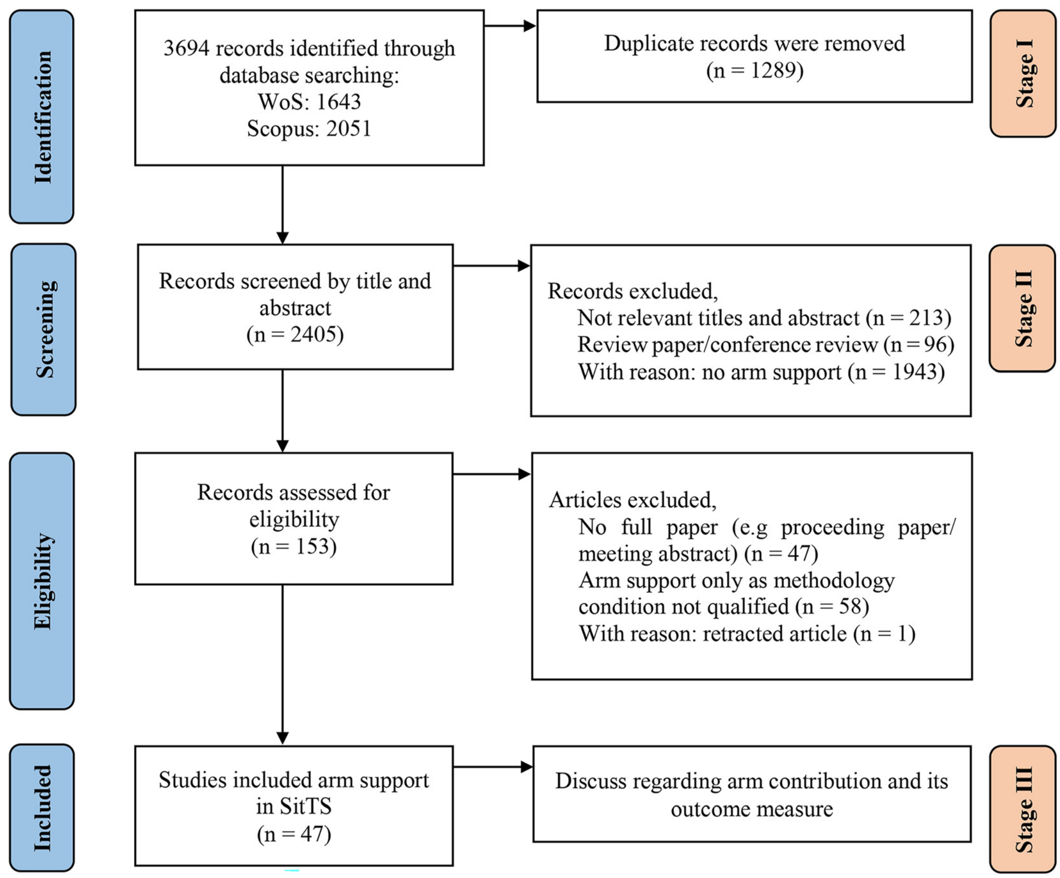

Figure 1: PRISMA flow diagram of the screening process for studies included in this systematic review.

Moving into the middle period, from 2005 to 2015, research efforts became more diverse and began to bridge the gap between technical and practical applications. Studies such as Saint-Bauzel et al., [9] and Robert et al., [10] explored assistive systems and modeling equations, while works like Leung and Yeh [11], Houck et al., [12] began validating these concepts in user-centered or clinical contexts. This period reflects an expansion in scope, with researchers moving beyond laboratory modeling into applied studies that addressed usability, safety, and the needs of real users.

From 2016 to 2022, the field experienced rapid growth and integration of new technologies, including robotics, wearable sensors, artificial intelligence, and rehabilitation frameworks. Recent contributions, such as those by Li et al., [13], Smith et al., [14], Kato et al., [15] and Abd Aziz et al., [16] demonstrate an emphasis on both technical advancement and clinical application. The trend continues into 2023–2025 with works by Kihara et al., [17], Oliveira et al., [18] Lau and Mombaur et al. [19], and Mahdi et al. [20], which reflect multidisciplinary approaches and a strong focus on both technical development and real-world clinical application.

Overall, the timeline illustrates a progression from foundational biomechanical and early technical investigations of arm-assisted SitTS studies in the initial years, to more advanced research emphasizing the importance of arm support in the mid-phase. In recent years, research on this topic has evolved toward integrated technical and clinical validations, incorporating multidisciplinary approaches. This shift highlights that the field has matured from theoretical groundwork to practical, patient-centered applications, with the current trajectory pointing toward clinically approved and widely usable rehabilitation and assistive technologies.

Summary of arm support contribution in SitTS

Of the 153 studies identified in Stage II, a total of 47 studies addressed the arm support contribution to the SitTS movement. These studies highlighted the role of the arms either as 'measurable parameters' or 'outcome measures' in clinical and technical studies, as shown in Table 2. 'Measurable

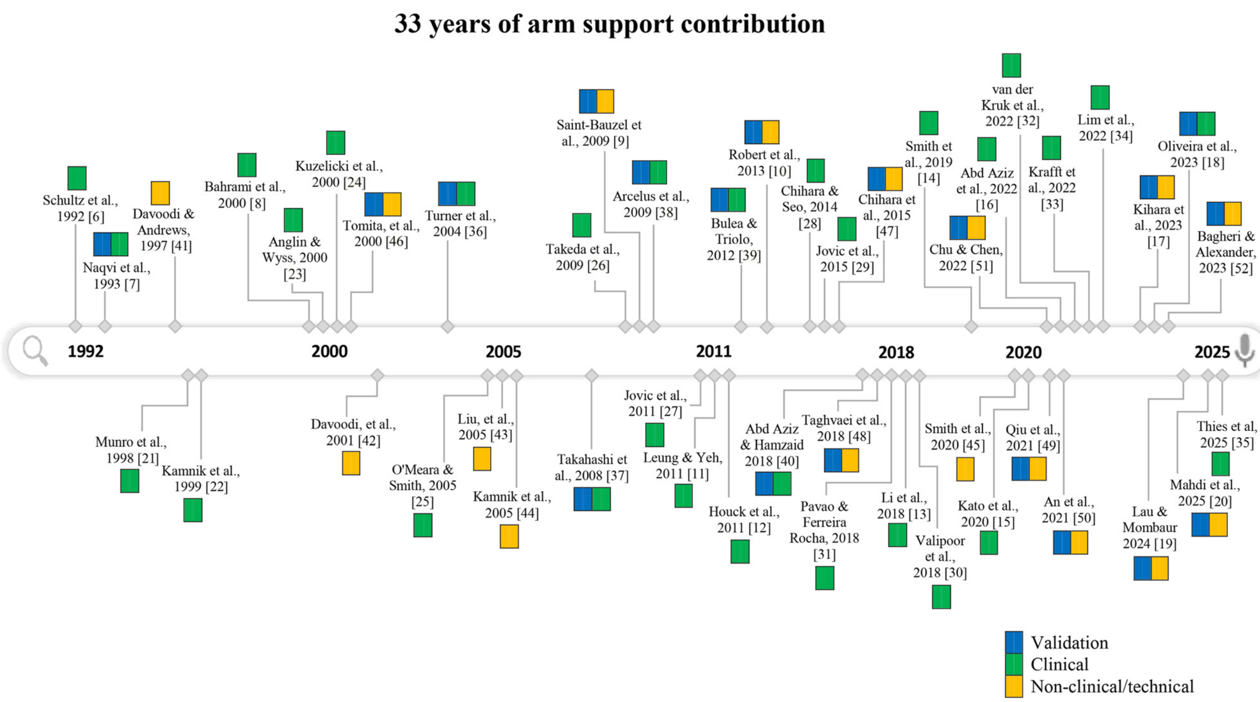

Figure 2: Timeline infographic of studies on arm support contribution in SitTS published between June 1992 and May 2025.

parameters' refer to the specific parameters observed and evaluated in detailed investigation, whereas 'outcome measures' refer to the specific results determined based on the objectives of the study. In this review, the term 'clinical aspect' refers to studies conducted with human participants to evaluate a range of healthcare-related measures or interventions, whereas 'non-clinical context' also referred to as 'technical study' denotes analyses or investigations involving mathematical, modelling, and simulation aspects of SitTS's arm support in rehabilitation research domain. In addition, the term 'validation perspective' refers to studies conducted to assess the accuracy and reliability of a tool, method, model, or instrument within its intended application context.

Resultant arm force

According to the summary in Figure 3, arm contribution serves as a dominant focus in this quantitative measurable parameter category. This parameter is prominently reported in clinical studies of SitTS movement, providing insights into compensatory strategies, especially in populations with impairments [6, 21, 27]. The study by Naqvi et al., [7], showed how the arm force was used to observe elderly arm strength between the lift-off and the point where the subject leaves the armrests. This finding is supported by another study by Turner et al., [36], which reported that the vertical force transmitted through each UL is typically 20–30 percent of the bodyweight. These parameters also enable researchers to determine the SitTS phases [24]. Arm force has been reported as highest at the moment of full knee extension during the activity.

Furthermore, O'Meara & Smith, & Takeda et al., reported that anterior assistance using arm support has a greater influence on SitTS performance than lateral assistance, as illustrated by the large magnitude of horizontal grab rail force [25, 26]. Interestingly, a study by Takahashi et al., demonstrated that a positive value indicates that the handrail was pulled as the participant used the handrail before seat-off and it was not used after the subject lifted his hips (indicated by a negative value) [37].

Ground reaction force

The force plates approach is commonly used to obtain one of the most essential factors in SitTS studies: ground reaction force (GRF) measurements (Figure 3). The study by Schultz et al., reported that the location of floor reaction forces varied among groups at liftoff during SitTS, with impaired elderly positioned most anteriorly, indicating different strategies for rising [6]. Similarly, Kuzelicki et al., used GRF parameters to distinguish the effects of different lower limb (LL) muscle stimulations, such as ankle plantar flexors and hip extensors, during the SitTS process [24].

Table 2: Studies of arm support contribution in arm assisted SitTS movement.

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Schultz et al. 1992 [6]	(1) Healthy young adults (n=17) (2) Healthy elderly adults (n=23) (3) Impaired elderly subjects (n=11)	Not specified.	(1) Mean peak hand force (2) Hand force angle (3) Net joint torques (4) Centre of Mass (CoM) position (5) Vertical floor reaction force location	(1) Joint torques at lift-off (hip, knee, ankle, shoulder) (2) Reaction force location **Findings:** Hands were not used to reduce joint torque requirements at lift-off, but to enhance postural stability during SitTS.		√	
Munro et al. 1998 [21]	Elderly female rheumatoid arthritis (RA) patient (n=12)	Four seat and arm-support conditions: (1) High seat height (540 mm) (2) Low seat height (450 mm) (3) Seat with ejector mechanism (4) Seat without ejector mechanism	(1) Ground Reaction Force (GRF): Vertical (F_y), anteroposterior (F_x) and mediolateral (F_z) (2) Vertical arm force	(1) Perceived exertion (RPE) (2) SitTS time (3) Kinematic variables (time to rise, trunk, knee ankle's angular displacement and angle at seat-off, Centre of Mass (CoM) horizontal velocity) (4) Kinetic variables (ankle and knee moments at set-off, vertical impulse) **Findings**: (1) Increased seat height and use of an ejector mechanism facilitated the SitTS movement among RA patients. (2) The ejector chair was preferred because it eliminated the need for a footstool, thereby reducing fall risk.		√	
Kamnik et al. 1998 [22]	Individuals with paraplegia (n=8)	Not specified.	(1) Foot force (2) Shoulder force (3) Joint forces and joint torque	(1) Comparison of force contributions between voluntary UL effort and electrically stimulated knee extensors. **Findings**: Upper-limb support provided most of the lifting force during SitTS. Three rising strategies were identified: (1) Primarily arm-dependent patients (knee extensor muscle is electrically stimulated). (2) Functional Electrical Stimulation (FES)-trained individuals who were		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type: Validation	Study type: Clinical	Study type: Technical/modelling
				able to recruit LL support more effectively. (3) Patients who used forward trunk momentum (similar to healthy controls).			
Bahrami et al. 2000 [8]	(1) Healthy adults (n=10) (2) Individuals with paraplegia (n=2)	Two fixed support bars positioned in front of the chair.	(1) Seat reaction force (2) GRF (3) Hand force	(1) SitTS duration (2) CoM trajectory (3) Whole-body linear momentum (4) Reaction forces (5) Joint torques (hip, knee) (6) Shoulder loads **Findings:** Healthy individuals used momentum transfer in combination with arm support to facilitate SitTS, whereas individuals with paraplegia were unable to generate forward momentum effectively and relied primarily on arm force.		√	
Anglin and Wyss 2000 [23]	Elderly adults (n=6)	A standard chair with armrests positioned 66 cm high and spaced 49 cm apart.	(1) Hand loads (2) Hand position (3) Arm joint angles (4) External shoulder moments	(1) External shoulder loading during SitTS. **Findings**: Sit average peak load=134 (37) n; Average peak load (x BW) = 0.19 (0.06)		√	
Kuzelicki et al. 2000 [24]	Individual with complete spinal cord injury (SCI) (n=1)	Not specified.	(1) Vertical handle reaction force (2) GRF (3) Seat reaction force	(1) Vertical handle reaction force across SitTS phases (2) Knee joint angle (3) GRF profile **Findings:** (1) The vertical arm support force was used to segment the standing-up movement into three phases. (2) Activating more muscle groups did not improve the efficiency of standing up compared to just using the knee extensors alone.		√	
O'Meara and Smith 2005 [25]	Elderly adults (n=12; 5 males, 7 females)	Eight arm-support conditions were tested, including four lateral and four anterior configurations:	(1) GRF (2) Grab-rail reaction force (3) Kinematic and kinetic data	(1) Grab-rail force characteristics (2) Anterior-Posterior hip, knee, ankle forces		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type: Validation	Study type: Clinical	Study type: Technical/modelling
		– Lateral supports: a) Vertical, b) 45° inclined, c) Horizontal with hand placed at 150 mm anterior to the seat, d) Horizontal with hand placed at 400 mm anterior to the seat edge. – Anterior supports: a) Vertical grab rail (one-hand) b) Vertical grab rail (two-hands) c) Horizontal grab rail (one-hand) d) Horizontal grab rail (two hands)		(3) Joints moments (Hip, knee, ankle) (4) Joint power outputs (Hip, knee, ankle) **Findings:** (1) Anterior grab rails provided greater assistance than lateral rails, producing higher posterior forces at the hand–rail interface. (2) Lateral assistance reduced contra-lateral peak joint forces and knee joint moments. (3) Vertical grab rails offered more effective support than horizontal configurations across SitTS conditions.			
Takeda et al. 2009 [26]	(1) Pregnant women (n=8) (2) Non pregnant women (n=8)	Four arm-support configurations were evaluated: (1) Distal bar (2) Proximal bar (3) Handrail (4) Armrest	(1) Handrail reaction force (2) Foot reaction force (3) Maximum lower-limb moments (4) Combined A-P GRF (5) SitTS duration	(1) Floor-reaction forces at the bar and legs (2) Trunk flexion RoM (3) Joint moments at the hip, knee, and ankle **Findings:** Bilateral armrests were found to be most effective in supporting SitTS performance.		√	
Jovic et al. 2011 [27]	Individual with paraplegia (n=1)	Two fixed handles mounted on parallel bars, with handle position adjusted according to the participant's preference to explore optimal voluntary trunk movement strategies.	(1) Arm-support force (2) Kinematic data of trunk and lower limbs	(1) Summation of absolute joint torques (ankle, knee, hip) **Findings:** The body should bend forward to use linear momentum of the trunk in sit-off phase, i.e. minimize the sum of joint torques and arm effort.		√	
Leung and Yeh 2011 [11]	Older adults (n=63) (1) Experienced walker users (n=31) (2) Inexperienced walker users (n=32)	A standard walker instrumented with four load cells and a twin-axis wrist goniometer.	(1) Arm-support force (2) Wrist joint kinematics	(1) Wrist deviation patterns (2) Vertical arm force **Findings:** (1) Significant wrist deviation occurred during walker-assisted SitTS.		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				(2) Right-hand dorsiflexion exceeded left-hand dorsiflexion across participants. (3) Male participants exerted higher vertical arm forces than females. (4) Experienced walker users exhibited greater ulnar deviation Experienced walker users demonstrated greater ulnar deviation during sitting and greater dorsiflexion during standing compared with inexperienced users, indicating adaptation of wrist mechanics with prolonged walker use.			
Houck et al. 2011 [12]	Older adults (n=28) (1) Hip-fracture recovery group (n=14) (2) Age-matched controls (n=14)	SitTS performed using an instrumented chair capable of measuring vertical ground reaction forces at the arms, trunk, and seat.	(1) GRF (2) Seat reaction force (3) Vertical forces at the arms and trunk	(1) Arm impulse representing upper-limb contribution during SitTS (2) Vertical GRF from the lower extremities **Findings:** Individuals recovering from a hip fracture demonstrated pronounced compensatory strategies during SitTS with increased use of arms, asymmetry in force output between the involved and uninvolved lower extremities.		√	
Chihara and Seo 2014 [28]	Young adult male aged 21–24 years (n=8)	Horizontal handrails positioned at systematically varied heights and distances to evaluate optimal handrail configuration for SitTS.	(1) EMG activity of the triceps brachii and tibialis anterior (2) User-reported usability ratings on a 1–7 scale (1=Very difficult, 7=Very easy)	(1) Subjective usability score (2) %MVC of the triceps brachii and tibialis anterior **Findings**: (1) A multi-objective optimisation framework was introduced to simultaneously assess upper- and lower-limb muscle demands and user-perceived difficulty. (2) The optimal handrail configuration for SitTS was identified at approximately 296 mm in height and 730 mm in horizontal distance, providing a balanced distribution		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				of muscle effort between the upper and lower limbs and ensuring favourable usability across participants.			
Jovic et al. 2015 [29]	Individuals with complete spinal cord injury (SCI) (n=6)	SitTS performed under four conditions involving differing timings of FES application: (1) Voluntary (no FES), (2) FES triggered 100–500 ms after the peak trunk acceleration. (3) FES triggered from 100 ms after to 100 ms before the peak trunk acceleration (4) FES triggered 100–500 ms before the peak trunk acceleration	(1) Trunk acceleration profile (2) Hand-support force	Resultant upper limb throughout the SitTS cycle. **Findings**: Arm-support forces were lowest when FES was initiated immediately before or near the moment of peak trunk acceleration.		√	
Valipoor et al. 2018 [30]	Older adult women aged >65 years (n=15)	Armrests were tested under varying design parameters: (1) Height: 13–33 cm (2) Diameter: 52–72 cm	(1) EMG activity of the dominant-side muscles: a) Biceps Brachii (BB) b) Triceps Brachii (TB) c) Vastus Lateralis (VL) d) Tibialis Anterior (TA) (2) Armrest reaction force (3) Video recording (data synchronization & duration time)	(1) Maximum muscle activity (2) Force at arm (3) Time taken for SitTS and StandTS **Findings:** Higher and wider armrests were associated with reduced muscle activation and lower perceived effort during SitTS.		√	
Pavao and Ferreira Rocha 2018 [31]	(1) Typical children (TC) (n=35; 18 males, 17 females) (2) Cerebral palsy (CP) (n=20; 13 males, 7 females)	Anterior hand support provided using a custom-designed table positioned for SitTS assistance.	Hand-support force	(1) Hand weight-bearing (2) Centre of Pressure (CoP) characteristics: a) A-P amplitude b) M-L amplitude c) CoP displacement d) CoP oscillation area e) Mean CoP oscillation velocity **Findings**: (1) Children with CP exhibited significantly greater hand weight-bearing during SitTS compared with typically developing children.		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				(2) The hand support reduced postural oscillation during the second phase of STS in both groups. (3) Within the CP group, greater weight bearing was related with lower postural oscillation in the beginning of SitTS.			
Li et al. 2018 [13]	Individuals with unilateral hemiparesis (n=30)	Six cane-placement conditions were tested (1) Regular cane (RC) a) Parallel to the ankle b) Parallel to the fifth toe c) 10 cm anterior to the toes. (2) Quad cane (QC) a) Parallel to the ankle, b) Parallel to the fifth toe c) 10 cm anterior of the toe. *Cane positioned on unaffected side.	(1) GRF at the feet (2) Cane reaction force measured using an instrumented weight scale	(1) Peak GRF expressed as a percentage of body weight (BW) (2) Maximum cane force expressed as a percentage of BW **Findings:** Positioning cane closer to the ankle and trunk reduced lower-limb loading and increased upper-limb force contribution.		√	
Smith et al. 2019 [14]	Healthy adult males i (n=27)	Not specified *Study focused on the biomechanical impact of simulated upper-limb muscle weakness during arm-assisted SitTS using combined experimental data and musculoskeletal (MSK) modelling.	(1) Hand-support forces (vertical & A-P components) (2) Muscle and joint reaction forces (JRF)	(1) Muscle weakness of UL – using MSK modelling **Findings:** Simulated weakness of the serratus anterior substantially impaired participants' ability to generate sufficient arm-support forces, leading to altered joint loading patterns and reduced stability during arm-assisted standing.		√	
Kato et al. 2020 [15]	Older adults aged >72 years (n=21; 11 males, 10 females)	SitTS was performed under two handrail configurations: (1) Conventional vertical handrail (CV) (2) Curved-angled handrail (CA)	(1) CoM displacement (2) CoM velocity (3) Handrail reaction forces in anterior–posterior and vertical directions *In terms of anterior-posterior & upward-downward	CoM kinematics and handrail loading characteristics during SitTS. **Findings**: Curved-angled handrails generated significantly higher anterior–posterior and vertical reaction forces compared with conventional vertical handrails ($p < 0.001$).		√	
						√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Abd Aziz et al. 2022 [16]	Individuals with incomplete SCI (n=2)	Instrumented arm support with walking frame (four legs)	(1) Mechanomyography (MMG) activity of the quadriceps (2) Knee joint angle (3) Arm, leg and chair reaction forces (4) Perceived stability and fatigue (qualitative feedback)	(1) Body weight contribution during SitTS **Findings**: (1) Upper- and lower-limb force contributions varied between participants and were strongly influenced by the lower-limb Medical Research Council (MRC) muscle grade (2) Arm-support forces increased markedly when lower-limb forces began to decline during the rising phase			
van der Kruk et al. 2022 [32]	(1) Young adults (n=27) (2) Older adults (n=23)	Arm support with four conditions: (1) Armrest push-off (2) Thigh push-off (3) Arm swing (4) No arm use	(1) Strength measures (isokinetic joint moments, handgrip) (2) Centre of Pressure (CoP) characteristics (3) Nerve conduction velocity and reflex latency (4) Joint range of motion (JROM) and proprioceptive acuity	(1) Identification of compensatory movement strategies used during STW transitions. **Findings**: Older adults frequently relied on arm-assisted strategies such as armrest push-off, which were more strongly associated with reduced ankle JROM and increased fear of falling rather than true lower-limb strength deficits.		√	
Krafft et al. 2022 [33]	Healthy young adults (n=20; 10 males, 10 females)	A custom-built robotic rollator simulator was used under two upper-limb support conditions: (1) Full support: participants grasped the rollator handles firmly (2) Touch support: participants lightly placed the hand on the palm support without gripping	(1) SitTS duration (2) CoP, displacement and sway area (3) LL joint angles (hip, knee and ankle)	(1) Time to complete the SitTS transition (2) CoP path length and sway area **Findings**: Full rollator support improved stability during SitTS, reflected by reduced preparation time for seat-off and smaller CoP path length and sway area.		√	
Lim et al. 2022 [34]	(1) Typically developing children (TDC) (n=17) (2) Children with CP (n=28)	Arm support with two conditions: (1) Hand on desk (std height) (2) Hand on desk (elbow flexion height)	(1) CoP (2) Reaction forces at the chair, feet, and desk (3) SitTS duration	(1) CoP sway (A-P & M-L) (2) 2.Peak body weight on desk at T1 (3) Time required to complete the SitTS task **Findings**: CP children demonstrated better performance and shortest time taken in the SitTS task when using a modified desk height.		√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Thies et al. 2025 [35]	Quantitative study: Healthy older adults (n=10; 6 males, 4 females) Qualitative study: Older adults (who used wheeled walking frame) (1) Care Home-based residents (n=7; 4 males, 3 females) (2) Community-living participants (n=6; M=1, F=5)	Two walking-frame configurations were evaluated: (1) Standard front-wheeled frame: handgrips positioned at the top (2) Prototype frame: novel lower-positioned handgrips mounted near the rear legs of the frame to facilitate SitTS and StandTS transfers	(1) Stability Margin (SM), computed via center of pressure and base of support. (2) User feedback through thematic interviews.	(1) Stability Margin (minimum and average values). (2) User perception of usefulness. **Findings**: (1) Stability margins values were either improved or equivalent when using the novel grips compared to standard methods. (2) Users felt the grips provided enhanced independence and stability during SitTS and StandTS transfers. (3) The prototype frame's novel lower handgrips safely supported older users during SitTS and StandTS transfers. (4) Stability was statistically equivalent or better with the novel frame compared to pushing off the chair seat or armrests. (5) The new handgrips were found to be useful by individuals living in the community and some care-home residents, promoting independence and control.		√	
Naqvi et al. 1993 [7]	Older adults (n=5)	Arm support (as a conditional method) involved the instrumentation, with strain gauges, of armrests of a prototype.	(1) Bilateral handrail force	Upper extremities strength **Findings**: Upper extremities strength found from the 5 subjects, with 66.94lb ± 29.55.	√	√	
Turner et al. 2004 [36]	Healthy adults (n=20)	Arm support with different seat heights and chair armrest heights. *To develop and test a new method for measuring UL loading and the corresponding GRF. Strain gauges were used to measure bending loads at the feet, as part of the system validation.	(1) Vertical load at hand (2) Force at feet	(1) Vertical load at hand – % of BW (2) Foot GRF – % of BW **Findings**: Vertical force transmitted through each UL approximately 20–30 % BW.	√	√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Takahashi et al. 2008 [37]	Individuals with Parkinson's disease (n=4)	Arm support with a moveable handrail. *To develop and test a SitTS assistance system with a moveable handrail, three handrail trajectories were evaluated.	(1) Chair reaction force (2) Foot reaction force (3) Handrail reaction force	(1) Centre of Gravity (CoG) – position and velocity profiles (2) Hip joint angle **Findings:** Moveable handrail with trajectory T1 (based on the shoulder motion of a non-Parkinson's syndrome standing up) can be used to assist individuals as they move from a seated to a standing position.	√	√	
Arcelus et al. 2009 [38]	Young adults (n=10) Older adults (n=11)	A commode chair equipped with pressure-sensing grab bars was used to unobtrusively evaluate arm-support use during SitTS transfers.	Force applied to the commode grab bars	(1) Transfer time: the duration during which the grab bars are used by the participant for weight transfer. (2) Maximum position: the location along the grab bar where the applied force is closest to the back of the commode (the most posterior position). (3) Time to maximum position: the time required to reach the most posterior force position (4) Position range: the distance along the bar over which the applied force is distributed during the transfer. (5) Maximum force exerted on the bar (6) Time to maximum force: the time required to reach the maximum force exerted on the bar (7) Force range: absolute difference in force applied to the bar during transfer. **Findings**: Elderly had slower and less forceful transfers compared to younger adults.	√	√	
Bulea and Triolo 2012 [39]	(1) Able bodied (n=3) for device verification (2) Individual with incomplete SCI (ASIA D) (n=1) for functional testing	Arm support with two conditions: (1) Vertical lift-assist walker (2) 2.A standard walker	(1) UL & LL kinematics (2) Foot GRF (3) Upper-extremity lift force	(1) Time to complete SitTS transition (2) Vertical torso displacement (3) Mean of LL lift force (4) Mean of UL lift force **Findings**: Compared with the standard walker, the lift-assist walker substantially reduced upper-limb	√	√	

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				loading during SitTS, as the gas-spring mechanism replaced much of the upper-extremity force required for rising.			
Abd Aziz and Hamzaid, 2018 [40]	Individuals with incomplete SCI (n=2)	Instrumented arm support with walking frame (four legs)	(1) GRF on feet (2) Force on arm (3) SitTS duration	(1) Centre of net UL force (2) Stability during SitTS (3) Fatigue during SitTS **Findings**: (1) Individuals with SCI completed voluntary SitTS more quickly; however, FES-assisted SitTS resulted in earlier fatigue and longer completion times. (2) Participants relied more on their right arm for support due to LL joint impairments.	√	√	
Oliveira et al. 2023 [18]	(1) Healthy volunteers (n=34) (2) Older adults from continuing care unit (n=16)	Two instrumented horizontal handrails with two conditions: (1) Chair positioned forward relative to the handrails (2) Chair positioned backward relative to the handrails	(1) SitTS duration (2) Sarcopenia Risk Screening Tool (SARC-F)	(1) UL force (2) SitTS duration **Findings:** Participants with LL motor limitation exhibited greater reliance on UL force during SitTS, indicating compensatory loading on the arms when leg strength is reduced.	√	√	
Davoodi and Andrews, 1997 [41]	Not applicable	Not specified. *To develop a computer model to design and compare controllers for FES-assisted standing up paraplegics.	Input controller: (1) Horizontal shoulder-joint position	Output controller: (1) Horizontal shoulder-joint force (2) Shoulder-joint moment **Findings**: Standing up without electrical stimulation requires a significant arm force of 550 n (7.86 n/kg BW) and a minimum knee joint moment of 110 Nm (1.57 Nm/kg BW).			√
Davoodi et al. 2001 [42]	Paraplegic patient (n=8)	Arm support frame height was adjusted according to patient's preferences. *To develop Artificial Neural Network (ANN) to predict voluntary arm forces.	(1) Forces & moment acting at UL & LL joint (2) Segmental mass centres (3) Angular positions and angular velocities of UL and LL joint	(1) Mean Absolute Error (2) Root Mean Square Error (3) Coefficient of Determination (R^2) (4) Correlation Coefficient **Findings**: The neural network model demonstrated high accuracy in predicting voluntary arm forces, indicating its potential as a reliable tool for improving FES systems.			√

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Liu et al. 2005 [43]	Healthy male participant (n=1)	Not specified. *To determine the optimal value parameters for a closed-loop control system that restores standing and sitting functions to paraplegics using FES.	(1) Maximum and average arm-support force (2) Knee-joint angular velocity (3) SitTS completion time	(1) Proportional gain (K_p) (2) Integral gain (K_i) **Findings**: Model simulations indicated that the most effective closed-loop control strategy for restoring SitTS using FES was achieved with an integral gain of K_i=0.5 and a proportional gain of K_p=0.			√
Kamnik et al. 2005 [44]	Individuals with paraplegia (n=8; 5 males, 3 females)	Arm support frame height was adjusted according to the patient's preferences. *To develop a nonlinear modelling.	(1) CoM trajectory (2) Seat reaction forces (3) Arm forces and torques applied to the right walker handle (4) GRF under the right foot (5) Motion kinematics of the body segments (6) Root mean square error (RMSE)	(1) Performance of ANN modeling technique (2) Sensor configuration effectiveness **Findings**: (1) The Gaussian Process (GP) model provided better modelling performance, achieving higher accuracy in predicting the CoM trajectory, but require greater computational cost. (2) The recommended configuration (six-axis handle force sensor and instrumented foot insole) achieved an average accuracy of 16 ± 1.8 mm horizontally and 39 ± 3.7 mm vertically.			√
Smith et al. 2020 [45]	(1) Young adults (18–35 years; n=30) (2) Middle-aged adults (40–60 years; n=30) (3) Older adults (>65 years; n=35)	Not specified. *To quantify the muscle and joint contact forces using musculoskeletal modelling during SitTS activity for older people.	(1) Vertical & A-P hand forces (2) Seat force plate measurements (3) Foot GRF (4) Kinematics (motion capture system) Input for musculoskeletal (two MSK models)	(1) Fugl-Meyer Assessment (FMA) score. (2) Model classification accuracy **Findings**: The older adults demonstrated significantly lower knee-extensor and joint forces than younger adults when not using armrest and showed higher shoulder joint contact forces when using armrests.			√
Tomita et al. 2000 [46]	(1) Healthy male in his 30 s (n=1) (2) Older adults (n=2)	Upper body support arm with fork-shaped link (driven by 3 joint). *To develop program for analyzing a LL joint torque.	(1) LL joint torques (2) LL joint positions (3) Reaction forces at the supporting arm (6-axial force sensor) (4) Floor reaction forces (chair-leg force plates)	(1) Sit-to-stand and stand-to-sit durations (2) Arm-support force (3) UL joint torque **Findings**: A minimum arm force (550 n) and knee joint moments (110 Nm) were	√		√

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				necessary to overcome gravitational resistance and ensure movement stability during the transition.			
Saint-Bauzel et al. 2009 [9]	(1) Individuals with multiple sclerosis (n=10; 6 males, 4 females) (2) Healthy adults (n=10)	Arm support from MONItor-noMAD (MONIMAD) prototype. *To develop a reactive robotized interface for LL rehabilitation of patients suffering from cerebellar ataxia disease.	(1) Postural data from hip, knee, and ankle goniometers and a trunk-mounted accelerometer (2) Handrail forces via force-instrumented handles (3) Foot reaction forces	(1) Effectiveness of the fuzzy-logic-based control system **Findings**: MONIMAD prototype significantly enhanced patients' ability to perform SitTS motions with greater stability and confidence.	√		√
Robert et al. 2013 [10]	Healthy young males (n=6)	Arm support through a right-hand handle instrumented to measure hand-contact forces. *To estimate unmeasured External Contact Loads (ECLs) acting on a system.	(1) Three force plates (positioned under each foot and under the seat) (2) Instrumented handle and frame-mounted sensors	(1) Force at handle (using inverse dynamics and optimization) **Findings**: The results form the proposed method were validated against experimental data, showing that the estimated ECLs closely matched the measured ground reaction forces.	√		√
Chihara et al. 2015 [47]	Healthy adults (n=12; 6 males, 6 females)	Participants used bilateral handles positioned symmetrically in the sagittal plane.	(1) LL joint torques (hip, knee, and ankle) (2) Hand-support forces (3) Segmental body masses (4) Torso and upper-leg angle at seat-off	(1) Minimum knee-joint torque (2) Optimum handle placement (3) Classification of handle-positions zones (4) Minimum resultant hand force required for SitTS **Findings**: Hip joint torque was reduced most significantly when UL assistance was applied.	√		√
Taghvaei et al. 2018 [48]	Healthy young adults (n=5)	Arm support by using walker. *To validate proposed dynamic model during SitTS to develop SitTS assistive robot.	(1) Handle forces of walker (three-axis force sensor) (2) Joints position (marker based visual analysis)	(1) LL joint angles (2) Force applied to the walker handles **Findings**: (1) A control-oriented dynamic model for SitTS motion with fixed support highlighted the derivation of dynamic equations through a multi–body model. (2) This approach enabled optimization of the motion trajectory for a specific objective, such as minimizing energy consumption or maximizing smoothness.	√		√

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
Qiu et al. 2021 [49]	Healthy young males (n=6) *Principal Motion Analysis (PMA) with 15 young males, including the previous 6. Supervised PMA – 1st principal – 2nd principal – 3rd principal (to examine human motion)	SitTS was performed using bilateral handrails spaced 0.7 m apart. Thirty-three experimental conditions were created by systematically varying: (1) Foot (ankle) position (A_1-A_3) (2) Hand-grip position (H_1-H_5) (3) Trunk tilt angle (15°, 30°, 45°) **Only feasible combinations of these conditions were tested.* *Easiest condition at 20deg, H1, A1. *Reference condition: 30deg, H3, A2. *Difficult condition: 15deg, H3, A2.	(1) Handrail reaction forces (2) Foot GRF (3) UL and LL joint angels obtained from motion capture	(1) Classification of Motor Impairment Fugl-Meyer Assessment (FMA) categories. (2) FMA score **Findings**: (1) The SitTS conditions synthesized by the three principle motions incurred a burden subjectively smaller than or comparable to the burdens in other conditions. (2) The correlation coefficients of the 1st, 2nd, and 3rd principle motions and subjective burden were 0.60, 0.27 and 0.19, respectively.	√		√
An et al. 2021 [50]	Subacute stroke patients with hemiplegia (n=15)	Arm support by using handrail. *To determine the degree of motor impairment in hemiplegic patients based on force applied to handrail.	(1) Handrail reaction force (2) Seat rection force measured using force plate (3) Whole-body kinematics captured via an optical motion analysis system	(1) Classification of motor impairment severity **Findings**: Patients with severe motor impairment applied greater force to the handrail and used it for a longer duration during SitTS transition compared with those with moderate impairment.	√		√
Chu and Chen 2022 [51]	Healthy young adults (n=30)	SitTS and StandTS transitions were performed using a wheelchair equipped with pressure sensors embedded in the armrests and seat surface.	(1) Armrest pressure (force) (2) Seat pressure (force) (3) SitTS and StandTS durations	(1) Time intervals for SitTS and StandTS transitions. **Findings**: SWAF demonstrated high temporal accuracy, achieving an average timing error of less than 150 ms when measuring SitTS and StandTS durations	√		√
Kihara et al. 2023 [17]	Healthy young adults males (n=10)	Vertical and horizontal handrails.	Anterior-posterior and upward-downward forces measured at: (1) Handrails (2) Buttocks (3) Feet	(1) Classification accuracy of motor function impairment **Findings**: (1) Horizontal handrails were mainly used to push upward, helping lift the body, while vertical handrails were used to pull and maintain front-to-back balance. (2) Under simulated impairment, participants applied greater	√		√

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				downward force to the horizontal handrails and relied on the vertical handrail for a longer duration to stabilize anterior–posterior motion. (3) Overall, horizontal handrails facilitated upward propulsion, while vertical handrails supported anterior–posterior control. (4) Improved motor function estimation accuracy with horizontal handrail (up to 78.0 %). Body force data (buttocks/feet) less effective for motor function classification.			
Bagheri and Alexander 2023 [52]	Not applicable	Two-handed, symmetrical handle configuration.	(1) Knee-, hip-, and ankle – joint torques (2) Horizontal and vertical hand forces (3) Resultant hand force required to assist SitTS (4) Handle positions at the seat-off phase	(1) Minimum required knee-joint torque **Findings**: Simulation results identified an optimal handle zone approximately 0.5 m above the ground and 0.1–0.3 m posterior to the ankle in a pre-standing posture.	√		√
Lau and Mombaur 2024 [19]	Healthy young adult female (n=1)	Arm support by using forearm crutches.	(1) Joint angles (Hip, knee, ankle, shoulder, and trunk/xiphisternal joint) (2) Joint torques (Hips, knees, ankles, trunk, and ULs) (3) GRF at the feet and crutches (4) SitTS duration (5) CoM trajectory	(1) Motor torque for hip and knee (2) Motion captures for SitTS **Findings**: (1) The TWIN exoskeleton required motor torques of at least 121 Nm at the hips and 140 Nm at the knees t perform SitTS independently, although partial assistance was feasible when the user contribute approximately 8 Nm at the hips and 50 Nm at the knees. (2) SitTS with the default TWIN trajectory relied heavily on upper-limb support, with crutch forces reaching up to 330 n. (3) The study also examined crutchless SitTS with TWIN to reduce	√		√

Table 2: (continued)

Study (author, year)	Population, n	Arm support characteristics	Measurable parameters	Outcome measures	Study type		
					Validation	Clinical	Technical/modelling
				upper-limb overuse associated with crutch-assisted movement.			
Mahdi et al. 2025 [20]	Healthy adults (n=10)	Robotic walker ("SkyWalker") with motorized adjustable handles for SitTS assistance. Consists of upper and lower-level handles.	(1) 3D kinematic data captured using Mediapipe skeleton tracking. (2) Key joint angles and body-segment positions during SitTS (3) Validation against Vicon motion capture. (14 kinematic features relevant for SitTS phase classification were selected, including joint angles and key point positions)	(1) Classification accuracy of SitTS phase detection (2) Joint positions, angles (feature accuracy) **Findings**: (1) Real-time classification of SitTS phases was feasible using 3D skeleton data. (2) Validation against Vicon confirmed that MediaPipe provides sufficiently accurate motion data for integration into assistive robotic applications such as SkyWalker.	√		√

It has also been shown that GRF parameters are useful for understanding additional kinematic and kinetic characteristics of the SitTS movement in diverse population groups [20–22, 25, 36, 39, 44–46, 49, 50]. In addition, one notable finding from a study by Takeda et al., reported a significant decrease in floor reaction forces when pregnant women used an armrest during SitTS. This decrease suggests that there was less load or pressure transmitted through the legs when rising with the armrest [37].

Besides that, findings from Houck et al., suggested that assessing vertical GRF during SitTS may enhance rehabilitation strategies by identifying movement compensations and their implications for recovery. Through their study on hip fractures categories, a significant correlation was identified between vertical GRF variables and established functional measures, such as Timed Up and Go (TUG) test [12]. Similarly, findings by Li et al., described that the use of a cane in individuals with hemiparesis significantly reduced peak ground reaction force by 3–9 % of body weight compared to when no cane was used [13].

Time taken for SitTS

Overall, a total of 13 studies addressed the time taken for arm-assisted SitTS movement. Oliveira et al. reported that persons with greater muscle mass loss took longer SitTS duration [18]. This finding is supported by Arcelus et al. [38], who reported that older persons demonstrated longer transfer times than younger adults. Additionally, Bahrami et al., described that patients with paraplegia required longer overall time to both voluntary and FES-assisted SitTS. However, in healthy adults, observations showed that strong arm support resulted in the longest duration to complete the task [8]. According to Lim et al., typically developing children had shorter SitTS duration compared to cerebral palsy (CP) patients [34]. The study by Valipoor et al., indicated that there were no significant variations in SitTS duration; however, these transitions were consistently completed in a shorter amount of time with the least amount of arm exertion [30]. Bulea and Triolo demonstrated that the length of SitTS varies depending on the type of walker used. SitTS performance in a Spinal Cord Injury (SCI) individual using a normal walker resulted in longer duration than using a lift walker [39]. In addition, ejector chair was found to result in longer SitTS duration in the Rheumatoid Arthritis (RA) population, as discussed by Munro et al. [21], which may be attributed to the discomfort and level of confident in the spring-assisted seat action during the task.

Meanwhile, in non-clinical studies, several investigations have identified the time taken to complete the SitTS task as a simple and widely used measurable parameter for assessing an

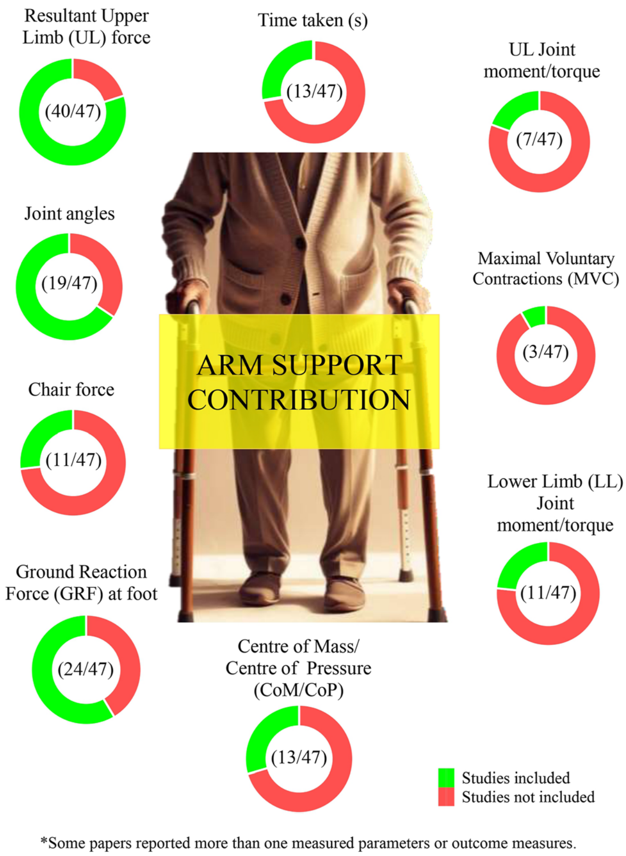

Figure 3: Summary of measurable parameters (technical studies) and outcome measures (technical and clinical) related to arm support contribution in SitTS. Green indicates the total number of studies assigned to each measurable parameters or outcome measure while pink indicates the studies that were not assigned.

individual's functional independence. A study by Chu and Chen developed a smart wheelchair system known as SWAF, in which SitTS time was utilized as a parameter for fall-risk assessment. Prolonged or inconsistent SitTS durations were associated with reduced muscle strength, impaired balance, and poor coordination in elderly individuals, all of which contribute to an increased risk of falls in this population [51]. In a separate study, Lau and Mombaur reported that the SitTS trajectory using the default TWIN exoskeleton with crutches recorded an average duration of 11.36 s, which was notably longer compared to when using the TWIN exoskeleton without crutches, where the SitTS motion was quicker, lasting only 4.3 s [19].

Joint angles

Based on Table 2, the included studies discussed various biomechanical aspects of joints and their angles, particularly during SitTS transfers, to understand human movement and the forces acting on the body [6, 26]. Additionally, different techniques of SitTS required specific joint angle ranges. For instance, rising from a chair with a cane involved distinct joint angle patterns, which highlight the importance of considering these ranges when designing assistive devices or rehabilitation programs [6, 23].

In fact, the studies concluded that arm contribution impacts joint angles and forces. Using handrails, walkers, or canes could alter the joint angles employed during SitTS transfers, potentially affecting muscle activation and joint loading. The studies emphasized the importance of optimizing assistive device design and placement to promote safe and efficient movement [21, 24, 26, 49]. By analyzing joint angles, particularly during dynamic SitTS activities, researchers sought to understand how the body maintains stability and utilizes momentum. The findings highlighted the importance of a detailed understanding of joint angles and their relationship to various factors, such as assistive devices, individual capabilities, and biomechanical principles [22].

Joint moment/torque

Joint torques and moments are related to joint angles. It is essential to consider not only the angles but also the torques generated at the joints. This comprehensive approach provides a more complete understanding of biomechanics and helps inform the development of effective interventions. When studying the SitTS transition, researchers often calculate net joint moments at seat-off, which is considered more comparable between subjects than peak moments. This is because seat-off is considered the most stressful point of the movement. One study found that, although net ankle moments at seat-off were similar to peak moments reported in other literature, net knee moments were relatively low. This suggests that subjects may have used strategies to protect their joints from high loading forces during this movement [21].

In this review, it is important to distinguish between net joint moments and external moments. Net joint moments refer to the moments acting at a joint, while external moments represent moments acting on the body from external sources, such as a chair or the ground. For instance, one study observed that the average peak external moments for subjects sitting down and lifting a suitcase ranged from 12.3 Nm to 27.9 Nm, with maximums significantly higher [23].

Other measured parameters

Maximal voluntary contractions (MVC)

There were a few studies that investigated maximal voluntary contractions (MVC) in relation to muscle activation. One such study examined the electromyographic (EMG) activity of the anterior deltoid, rectus femoris, triceps brachii and tibialis anterior. The findings indicated that %MVC of the anterior deltoid and rectus femoris was unaffected by handrail position. However, %MVC of the triceps brachii increased when using higher and closer handrail positions [28]. In another study, Valipoor et al. explored the influence of dominant-side MVC on EMG on UL muscle activation during arm-assisted SitTS movements. Their results demonstrated that the triceps brachii showed greater activation than the biceps brachii. In contrast, analysis of the LL muscles revealed similar activation levels between the tibialis anterior and vastus lateralis [30].

To date, only one study specifically examined the mechanomyography (MMG) response of the quadriceps muscle during assisted SitTS movement. The analysis revealed that the amplitude of its root mean square was positively correlated with quadriceps muscle contraction and muscle force production. Notably, the highest peak amplitude of normalized root mean square occurred between Phase 1 and Phase 2 of the SitTS cycle, indicating this to be the point of maximal quadriceps force output [16].

Centre of pressure (CoP) and Centre of mass (CoM)

The CoP represents the point of application of the resultant ground reaction forces from the seat, arms, and feet. In this review, these parameters were discussed in two studies involving individuals with cerebral palsy (CP) [31, 34] which contributed to understanding how young individuals with CP coordinate their muscle activity to complete SitTS movement. The postural control analyses the total area of anterior–posterior and mediolateral CoP displacement and velocity during the exercise. In a comparative study, handrail shape did not affect the displacement or velocity of the CoM during SitTS. Furthermore, individuals may require less forward CoM translation to achieve dynamic stability before rising if their trunk flexion is decreased [15].

Discussion

This review synthesizes findings from 47 studies addressing the contribution of arm support to SitTS movements, highlighting the significant role of the arms in both clinical and technical contexts. Understanding these measurements helps researchers assess how much arm force is required to assist individuals in successfully performing SitTS, especially when lower body strength is compromised. In addition, identification of SitTS phases can be derived. Research protocols in previous studies have defined distinct phases within the SitTS movement (such as lift-off, knee extension, and seat-off). By examining force parameters at different phases, researchers can determine when arm support is most needed, such as during full knee extension, when arm force is typically highest. This phase-based understanding provides for a more nuanced view of arm support's role throughout the movement.

Through studies conducted by O'Meara & Smith [43] and Takeda et al. [26] different types of arm support (anterior vs. lateral) can be examined, as those influence SitTS performance. It was also observed that anterior arm support, such as a front-facing grab rail, provides greater assistance compared to lateral support. This finding aligns with the idea that specific arm positions and forces are more advantageous during certain phases of SitTS. Additionally, studies such as Takahashi et al., [37] revealed that individuals pull on the handrail most during the pre-seat-off phase, which occurs before their hips are lifted. This dynamic suggests that arm support may be more critical in the initial stages of SitTS, guiding how arm support technologies and interventions may be better designed for those stages.

However, in most non-clinical arm assisted SitTS research, the focus has primarily been on the arm-force parameter to assist researchers in developing mathematical models and human body simulations of the SitTS movement. Davoodi & Andrews, in 1997 & 2001, established a controller for FES-assisted standing-up and an artificial neural network (ANN) for individuals with paraplegia, in which voluntary arm forces required to stand without FES were estimated as an outcome measure. These approaches may be integrated with other musculoskeletal models of the LLs to develop a realistic cybernetic model of individuals with paraplegia [42].

In addition, Liu et al. [43] discussed arm force as one of the feedback signals used to adjust the intensity of electrical stimulation of the leg muscles in a closed loop control system during standing and sitting activities in individuals with paraplegia. Other studies also highlighted that the force applied at the arms is an important measurement for developing various types of mathematical models related to standing movement and for prototyping an assistive SitTS robot [44, 45, 48]. Furthermore, these measured parameters helped An et al. [50] determine the degree of motor impairment in hemiplegic patients, and they could also detect long-term patient recovery. The strength of their study was that it did not require attaching any sensors to the patient's body during the motion, thereby enhancing its clinical practicality.

Several studies evaluating MVC have examined muscle effort during arm-assisted SitTS activities. In one study examining handrail position, %MVC of the triceps brachii and tibialis anterior were significantly influenced by handrail height and distance, demonstrating a trade-off in load distribution between the UL and LL. Chihara and Seo et al., reported that while the anterior deltoid and rectus femoris were only partially affected, an optimal compromise between UL and LL effort occurred at approximately 296 mm in height and 730 mm in distance [28].

In another study involving elderly women and a safer chair design, EMG analysis showed that the biceps brachii was activated at 7–18 % MVC, the triceps brachii at 14–45 % MVC, and LL muscles such as the vastus lateralis and tibialis anterior reached 27–45 % MVC, depending on the SitTS phase. The findings also revealed non-linear effects of armrest dimensions, where minimal muscular effort occurred with higher and wider armrests compared to conventional chairs.

Overall, MVC-based EMG outcomes consistently demonstrated that support design significantly influenced muscle demand. Higher and closer supports shifted the load toward the UL, while lower or more distant supports increase LL activation. These results highlight the importance of optimizing support dimensions to achieve balanced load distribution and reduce muscular effort during SitTS transitions.

Population-specific arm assistance strategies in SitTS transitions

Understanding different populations involved in arm assisted SitTS transitions may significantly inform the design of effective SitTS exercise and rehabilitation strategies that enhance performance and promote functional independence. Among healthy individuals, especially young adults, studies have established normative baselines for biomechanical parameters and muscle activation patterns [6, 7, 11, 12, 15, 25, 30, 38]. In contrast, elderly participants consistently employ compensatory arm-support strategies to counteract age-related declines in muscle strength, joint stability, and balance [18, 32, 35]. For groups with musculoskeletal disorders, such as RA or post-orthopedic surgery conditions, outcomes commonly involve prolonged SitTS times and increased UL reliance due to pain, joint stiffness, or weakness [21]. Additionally, children and pregnant women represent special populations where safety, adaptability, and ergonomic support take priority over biomechanical output. These studies have explored how physical changes, whether growth-related or gestational affect posture, control, and the need for assistive hand placement.

Neurological populations present a more nuanced profile for arm assisted SitTS analysis. Studies involving individuals with SCI and stroke typically focused on kinetic parameters, particularly UL forces and joint torque. These parameters were measured to evaluate compensatory mechanisms and the effectiveness of assistive interventions. In contrast, studies on CP and Parkinson's disease more commonly focused on dynamic balance and postural stability, using measures such as CoP and center of mass (CoM) trajectories [31, 34, 37].

A broader trend distinguishes clinical populations (elderly, CP, stroke, RA and SCI) through investigations that focus on functional outcomes, including SitTS time, UL effort, and balance control. In comparison, technical studies involving healthy participants or simulations typically prioritized mechanical variables such as GRF, joint torques, and musculoskeletal modelling. These differentiated approaches highlight the importance of tailoring arm assisted SitTS assessments and interventions to the unique capabilities, challenges, and rehabilitation goals of each population.

For practical and clinical purposes, parameters such as joint angles and time taken are advisable because these parameters are not only clinically relevant but also easier to measure and interpret compared to more complex force measurements. This is because of their ease of administration, minimal equipment requirements, and strong correlation with LL strength and mobility. SitTS time provides a quick and objective way to evaluate physical performance, especially in older adults or individuals undergoing rehabilitation. Furthermore, shorter completion times are typically associated with better functional status, while prolonged times may indicate underlying impairments, such as muscle weakness, balance deficits, or reduced neuromuscular coordination [19, 43, 51].

Arm contribution as "hidden assistance" in SitTS

Collectively, these findings indicate that UL involvement not only represents a compensatory strategy but also functions as a substantial redistribution of mechanical demand in the SitTS task. Across studies, arm use was broadly categorized based on the type of assistance provided: fixed supports (i.e. armrests, handrails), mobile aids (i.e. walkers, canes) or momentum-based strategies without external support. Across all assistance types, UL forces often contributed a substantial proportion of body weight support. This reliance was consistently observed in frail older adults and was particularly pronounced in individuals with neurological impairments, such as paraplegia or SCI. Importantly, this mechanical contribution was often clinically "hidden" because SitTS performance was commonly classified as independent when no hands-on assistance is provided.

For fixed supports, it was reported that vertical arm forces were particularly high. In individuals with paraplegia, peak vertical forces applied to support bars during SitTS ranged from approximately 65–70 % of body weight when FES was used, and they increased to approximately 85 % when FES was not used [8]. Individuals with complete SCI exhibited similarly high vertical arm forces ranging from of 84–89 % of body weight [29]. In contrast, vertical arm forces in incomplete SCI spanned a wide range (approximately 25–73 % of body weight), likely reflecting heterogeneity in neurological impairment and functional capacity [16, 39]. Mobile aids such as canes generally contributed lower vertical forces, with values of approximately 4–9% of body weight reported in individuals with unilateral hemiparesis [13]. In addition, grab rail use was associated with intermediate vertical arm forces of approximately 15–30 % of body weight across different populations, including healthy adults, pregnant women, individuals with CP [18, 26, 31, 36].

In a nutshell, these findings support the concept of hidden arm assistance, whereby SitTS tasks that appear independent may, in fact, rely substantially on UL support, thereby masking underlying limitations in LL strength or motor control. Consequently, functional assessments and rehabilitation protocols that ignore arm contributions, or that allow unrestricted arm use, were likely to overestimate LL capacity, motor recovery, and overall functional independence. SitTS assessment and training should, therefore, explicitly measure, control, or limit arm involvement to ensure that observed performance accurately reflects LL function.

For research settings or in-depth biomechanical studies, researchers should utilize advanced tools that incorporate measurements of arm, seat, and foot forces to provide a comprehensive understanding of the SitTS movement. However, the choice of tools was guided by the study's objectives, resources available, and the specific needs of the intervention.

In conclusion, this review emphasizes the balance between practical clinical measures and more detailed biomechanical assessments. Joint angles and time taken were the most practical for clinical use, while advanced measurements, like MVC, CoP, and CoM, offered additional insights for research and intervention studies. By choosing the appropriate methods based on the context and objectives, practitioners and researchers could better evaluate and enhance SitTS interventions and support more effective rehabilitation strategies.

Acknowledgments: The authors acknowledge the Ministry of Higher Education Fundamental Research Grant FRGS/1/2024/SKK01/UM/02/3.

Research ethics: Not applicable.
Informed consent: Not applicable.
Author contributions: MAA responsible in conceptualization, methodology, and initial draft of the manuscript. Responsible for reviewing all papers and contributing to the analysis and interpretation of the data. NAH responsible in conceptualization and assisted with structuring and organizing the content of manuscript. Contributed to the analysis of the data, reviewing papers, and provided significant revisions and suggestions during the review process. HM, NAM contributed in analysis of the data, reviewing papers, and providing overall direction of the paper and provided significant revisions and suggestions during the review process. All authors reviewed the article.
Use of Large Language Models, AI and Machine Learning Tools: Minimal for language editing.
Conflict of interest: The authors declare no competing interest.
Research funding: FRGS/1/2024/SKK01/UM/02/3.
Data availability: https://drive.google.com/drive/folders/1-zXEFNf181rRV5ARBOjriB6QPenIia-6.

References

1. Boukadida A, Piotte F, Dehail P, Nadeau S. Determinants of Sit-To-Stand tasks in individuals with hemiparesis post stroke: a review. Ann Phys Rehabil Med 2015;58:167–72.
2. Jeon W, Hsiao HY, Griffin L. Effects of different initial foot positions on kinematics, muscle activation patterns, and postural control during a Sit-To-Stand in younger and older adults. J Biomech 2021;117. https://doi.org/10.1016/j.jbiomech.2021.110251.
3. Chaovalit S, Taylor NF, Dodd KJ. Sit-to-Stand exercise programs improve Sit-to-Stand performance in people with physical impairments due to health conditions: a systematic review and meta-analysis. Disabil Rehabil 2020;42:1202–11.
4. Janssen WGM, Bussmann HBJ, Stam HJ. Determinants of the Sit-To-Stand movement: a review. Phys Ther 2002;82:866–79.
5. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. bmj 2021;372.
6. Schultz AB, Alexander NB, Ashtonmiller JA. Biomechanical analyses of rising from a chair. J Biomech 1992;25:1383–91.
7. Naqvi SAA, Stobbe TJ, Stanley CF. A methodology to assess the upper extremity strength in a chair egress posture. Appl Ergon 1993;24:125–9.
8. Bahrami F, Riener R, Jabedar-Maralani P, Schmidt G. Biomechanical analysis of Sit-To-Stand transfer in healthy and paraplegic subjects. Clin BioMech 2000;15:123–33.
9. Saint-Bauzel L, Pasqui V, Monteil I. A reactive robotized interface for lower limb rehabilitation: clinical results. IEEE Trans Robot 2009;25: 583–92.
10. Robert T, Causse J, Monnier G. Estimation of external contact loads using an inverse dynamics and optimization approach: general method and application to Sit-To-Stand maneuvers. J Biomech 2013;46:2220–7.
11. Leung CY, Yeh PC. Vertical force and wrist deviation angle when using a walker to stand up and sit down. Percept Mot Skills 2011;113:229–41.

12. Houck J, Kneiss J, Bukata SV, Puzas JE. Analysis of vertical ground reaction force variables during a Sit To Stand task in participants recovering from a hip fracture. Clin BioMech 2011;26:470–6.
13. Li TC, Tu KH, Shiue HS, Lin MR. Effects of cane use and position on performance of the Sit-To-Stand task in stroke patients. Am J Phys Med Rehabil 2018;97:476–81.
14. Smith SHL, Reilly P, Bull AMJ. Serratus anterior weakness is a key determinant of arm-assisted standing difficulties. Med Eng Phys 2019; 74:41–8.
15. Kato T, Sekiguchi Y, Honda K, Izumi S-I, Kanetaka H. Comparison of handrail reaction forces between two different handrails during Sit-To-Stand movement in the elderly. Clin BioMech 2020;80. https://doi.org/10.1016/j.clinbiomech.2020.105130.
16. Abd Aziz M, Hamzaid NA, Hasnan N. Quantifying arms and legs contributions during repetitive electrically-assisted Sit-To-Stand exercise in paraplegics: a pilot study. J Vis Exp 2022;e63149.
17. Kihara R, An Q, Takita K, Ishiguro S, Nakashima K, Kurazume R, editors, et al. Analysis of Force Applied to Horizontal and Vertical Handrails with Impaired Motor Function. IEEE/SICE International Symposium on System Integration (SII). Atlanta, GA: Institute of Electrical and Electronics Engineers (IEEE); 2023.
18. Oliveira N, Carvalho F, Laíns J, Rasteiro D, Roseiro L. Development of a biomechanical device for parameter quantification associated with the Sit-To-Stand movement. Sensors 2023;23:1837.
19. Lau JCL, Mombaur K. Can lower-limb exoskeletons support sit-to-stand motions in frail elderly without crutches? A study combining optimal control and motion capture. Front Neurorob 2024;18. https://doi.org/10.3389/fnbot.2024.1348029.
20. Mahdi A, Dong ZH, Lin JFS, Hu Y, Hirata Y, Mombaur K. Real-time Sit-To-Stand phase classification with a Mobile assistive robot from close proximity utilizing 3D visual skeleton recognition. IEEE Rob Autom Lett 2025;10:2160–7.
21. Munro BJ, Steele JR, Bashford GM, Ryan M, Britten N. A kinematic and kinetic analysis of the Sit-To-Stand transfer using an ejector chair: implications for elderly rheumatoid arthritic patients. J Biomech 1998; 31:263–71.
22. Kamnik R, Bajd T, Kralj A. Functional electrical stimulation and arm supported Sit-To-Stand transfer after paraplegia: a study of kinetic parameters. Artif Organs 1999;23:413–7.
23. Anglin C, Wyss UP. Arm motion and load analysis of Sit-To-Stand, Stand-To-Sit, cane walking and lifting. Clin BioMech 2000;15:441–8.
24. Kuzelicki J, Bajd T, Kamnik R, Obreza P, Benko H, editors. FES assisted sit-to-stand transfer in paraplegic person. 22nd Annual International Conference of the IEEE-Engineering-in-Medicine-and-Biology-Society. Chicago, Il: Institute of Electrical and Electronics Engineers (IEEE); 2000.
25. O'Meara DM, Smith RM. Differences between grab rail position and orientation during the assisted Sit-To-Stand for able-bodied older adults. J Appl Biomech 2005;21:57–71.
26. Takeda K, Katsuhira J, Takano A. Effects of handrail use during sit-to-stand in the third trimester. Int J Ind Ergon 2009;39:988–94.
27. Jovic J, Fraisse P, Coste CA, Bonnet V, Fattal C. Ieee, editors. Improving valid and deficient body segment coordination to improve FES-Assisted sit-to-stand in paraplegic subjects. In: IEEE International Conference on Rehabilitation Robotics (ICORR)/International Neurorehabilitation Symposium (INRS)/International Conference on Virtual Rehabilitation (ICVR). Zurich, Switzerland: ETH Zurich; 2011.
28. Chihara T, Seo A. Evaluation of multiple muscle loads through multi-objective optimization with prediction of subjective satisfaction level: illustration by an application to handrail position for standing. Appl Ergon 2014;45:261–9.
29. Jovic J, Azevedo Coste C, Fraisse P, Henkous S, Fattal C. Coordinating upper and lower body during FES-assisted transfers in persons with spinal cord injury in order to reduce arm support. Neuromodulation 2015;18:736–42.
30. Valipoor S, Pati D, Stock MS, Bazuin D. Safer chairs for elderly patients: design evaluation using electromyography and force measurement. Ergonomics 2018;61:902–12.
31. Pavao SL, Ferreira Rocha NAC. Hands support and postural oscillation during sit-to-stand movement in children with cerebral palsy and typical children. J Mot Behav 2018;50:194–201.
32. van der Kruk E, Strutton P, Koizia LJ, Fertleman M, Reilly P, Bull AMJ. Why do older adults stand-up differently to young adults? investigation of compensatory movement strategies in sit-to-walk. Npj Aging 2022;8. https://doi.org/10.1038/s41514-022-00094-x.
33. Krafft FC, Herzog M, Stein T, Sloot LH. Young individuals are more stable and stand more upright when using rollator assistance during standing up and sitting Down. Front Bioeng Biotechnol 2022;10. https://doi.org/10.3389/fbioe.2022.876349.
34. Lim HK, Ko J, Lee D, Han DU. Modified desk height helps children with cerebral palsy perform Sit-To-Stand. Disabil Rehabil Assist Technol 2022;17:221–7.
35. Thies SB, Bevan S, Wassall M, Mootien CP, Kenney L, Howard D. Can a novel set of handgrips on a walking frame increase stability and support users when transferring to/from a chair? BMC Geriatr 2025;25. https://doi.org/10.1186/s12877-025-05754-7.
36. Turner HC, Yate RM, Giddins GEB, Miles AW. A method for measuring vertical forces applied to the upper limb during Sit-To-Stand. Proc IME H J Eng Med 2004;218:461–5.
37. Takahashi Y, Nitta O, Tomuro K, Komeda T, editors. Development of a sit-to-stand assistance system. 11th International Conference on Computers Helping People with Special Needs. Linz, AUSTRIA: Springer-Verlag; 2008.
38. Arcelus A, Holtzman M, Goubran R, Sveistrup H, Guitard P, Knoefel F, editors, et al. Analysis of commode grab bar usage for the monitoring of older adults in the smart home environment. Annual International Conference of the IEEE-Engineering-in-Medicine-and-Biology-Society. Minneapolis, MN: Institute of Electrical and Electronics Engineers (IEEE); 2009.
39. Bulea TC, Triolo RJ. Design and experimental evaluation of a vertical lift walker for sit-to-stand transition assistance. J Med Devices-Trans ASME 2012;6. https://doi.org/10.1115/1.4005786.
40. Abd Aziz M, Hamzaid NA, editors. FES Standing: The Effect of Arm Support on Stability and Fatigue During Sit-to-Stand Manoeuvres in SCI Individuals. 2nd International Conference for Innovation in Biomedical Engineering and Life Sciences (ICIBEL). MALAYSIA: Springer; 2018.
41. Davoodi R, Andrews BJ, editors. A model of FES standing-up in paraplegics including upper limb interaction and closed-form dynamics. 18th Annual International Conference of IEEE Engineering-in-Medicine-amd-Biology-Society. Amsterdam, Netherlands: Institute of Electrical and Electronics Engineers (IEEE); 1997.
42. Davoodi R, Kamnik R, Andrews B, Bajd T. Predicting the voluntary arm forces in FES-assisted standing up using neural networks. Biol Cybern 2001;85:133–43.
43. Liu CL, Yu CH, Chen SC, Chen CH. Evaluation of closed-loop control system for restoring standing and sitting functions by functional electrical stimulation. Biomed Eng Appl Basis Commun 2005;17:19–26.
44. Kamnik R, Shi JQ, Murray-Smith RK, Bajd T. Nonlinear modeling of FES-supported standing-up in paraplegia for selection of feedback sensors. IEEE Trans Neural Syst Rehabil Eng 2005;13:40–52.
45. Smith SHL, Reilly P, Bull AMJ. A musculoskeletal modelling approach to explain sit-to-stand difficulties in older people due to changes in

muscle recruitment and movement strategies. J Biomech 2020;98. https://doi.org/10.1016/j.jbiomech.2019.109451.
46. Tomita M, Ogiso T, Nemoto Y, Fujie MG. A study on the path of an upper-body support arm used for assisting standing-up and sitting-down motion. JSME Int J Ser C Mech Syst Mach Elem Manuf 2000;43: 949–56.
47. Chihara T, Fukuchi N, Seo A. Optimum position and orientation of handrail for sit-to-stand movement. J Adv Mech Des Syst Manuf 2015;9. https://doi.org/10.1299/jamdsm.2015jamdsm0036.
48. Taghvaei S, Tavasoli A, Feizi N, Rajestari Z, Abdi M. A control-oriented dynamic model for sit-to-stand motion with fixed support. Proc Inst Mech Eng - Part K J Multi-body Dyn 2018;232:265–73.
49. Qiu CY, Okamoto S, Akiyama Y, Yamada Y. Application of supervised principal motion analysis to evaluate subjectively easy sit-to-stand motion of healthy people. IEEE Access 2021;9:73251–61.
50. An Q, Yang NJ, Yamakawa H, Kogami H, Yoshida K, Wang RX, et al. Classification of motor impairments of post-stroke patients based on force applied to a handrail. IEEE Trans Neural Syst Rehabil Eng 2021;29: 2399–406.
51. Chu ETH, Chen KJ. SWAF: smart wheelchair for fall risk assessment. J Syst Architect 2022;131. https://doi.org/10.1016/j.sysarc.2022.102694.
52. Bagheri A, Alexander K. Optimum handle location for the hand-assisted sit-to-stand transition: a tool. Biomechanics 2023;3:267–77.