DESIGN OF A LOAD SHARING SIT-TO-STAND ASSISTIVE TEST BED

J. Jeyasurya, T. Lai, O. Patil, E. Pospisil, H.F. M. Van der Loos, E. A. Croft, A. Hodgson
CARIS Laboratory Department of Mechanical Engineering, University of British Columbia

INTRODUCTION

Rising from a chair is a basic requirement of maintaining independence for ambulatory older adults. Since an estimated 2 million non-institutionalized persons in the USA over the age of 65 have difficulty rising from a chair [1], assistive devices to aid with independent transfer from a seated to standing position can potentially have a high impact in enabling older persons to maintain their independence.

There are a number of assistive devices for independent Sit-To-Stand (STS). Non-powered devices include grab bars and standing frames that serve to stabilize users as they rise. Powered stand devices include walkers with powered standing assists that guide the arms of users [2], lift cushions and lift chairs that assist users at the buttocks [3] (also known as ejector chairs), and sling type assists, which provide assistance at the waist of users and are used primarily in institutional settings [4].

Despite the wide range of available STS devices, it is frequently unclear which device is the most appropriate to use for a given patient. For example, concerns exist among rehabilitation professionals that habitual use of standing assistance, namely through ejector chairs, may contribute to accelerated muscular degeneration due to muscle disuse [5]. While disability resulting from long-term ejector chair use has not been well studied in the literature [3], it is known that encouraging activity among mobility-impaired people can help prevent further disability and mortality [6]. Few STS aids actively engage the user's muscles in the motion performance, with only the devices developed by [7] and [8] being identified as active load-sharing devices. For these reasons, it is important to better understand the biomechanics of the STS transition.

In this paper, we describe the design of a Load-Sharing Sit-to-Stand Assistive Test Bed for independent transfer and present results from preliminary experiments with one healthy subject. The purpose of the test bed is to evaluate multiple assist locations based on published and practiced methods of both human- and mechanically-assisted STS. In particular, this test bed will help us assess the trajectory, stability and load sharing produced by different assist mechanisms. Results from experiments will help characterize the biomechanics of assisted STS transfers, providing guidance in developing procedures and design criteria for new institutional and consumer devices.

SIT-TO-STAND TEST BED DESIGN

Most existing powered stand assist devices provide assistance at the arms, waist, or buttocks. The STS test bed (Figure 1) includes powered mechanisms that can assist users to a standing position using each of these modalities. The following sections describe the assist mechanisms.

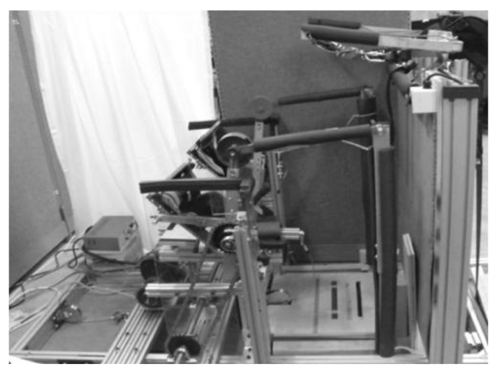

Figure 1: Sit-to-stand test bed

Arm Assist

The arm assist consists of dual 4-bar mechanisms that guide the users' elbows through a specified STS trajectory. The therapist-preferred "momentum transfer" (MT) strategy was implemented on the test bed [9]. This trajectory was obtained through experiments in which a subject fitted with orientation sensors performed an unassisted chair rise. A biomechanical model developed in MATLAB™ was used to compute a set of elbow trajectories for a range of subject heights, and the adjustable link lengths of the 4-bar mechanism were selected to accommodate this range. For the arm assist mechanism, the motor uses a roller-chain drive to power a jack-shaft, which drives a pair of follower chains. These in turn drive the left and right four-bar mechanisms through linkages L1 (see Figure 2). Each 4-bar mechanism interfaces with the user at the elbow via an L-shaped cradle attached to the second linkage (L2). The cradle is free to pivot about the attachment point.

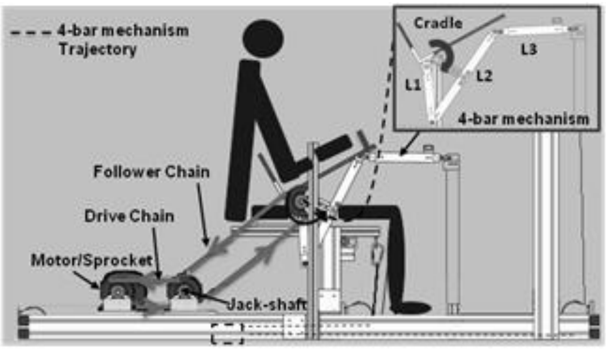

Figure 2: Arm Assist Configuration. The elbow path is shown as a dotted line.

Waist Assist

The waist assist mechanism, representative of many institutional lifts, uses a U-shaped lever arm that rotates about a pivot in front of the subject. The lever arm provides assistance through a pair of straps attached between the ends of the "U" and a padded transfer harness at the waist. The lever arm is powered by the motor through a steel cable run over pulleys and along the floor under the test bed (see Figure 3). The subject is pulled forward to a standing position as the lever arm is rotated upwards.

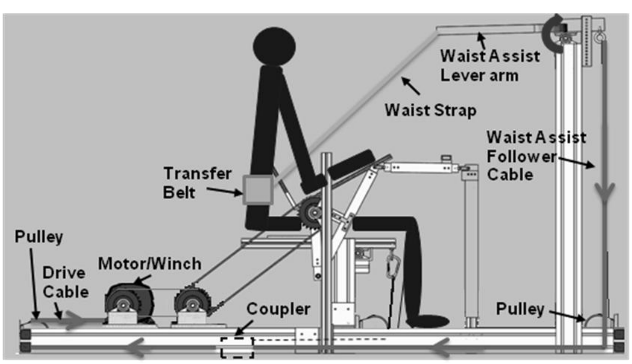

Figure 3: Waist Assist Configuration

Buttocks Assist

The buttocks assist mechanism, representative of chair-mounted lifting aids, utilizes a hinged seat on a lever arm rotating about a pivot under the subject's knees (see Figure 4). The winch on the motor shaft transmits power from the motor via the drive cable and pulley to the buttocks assist. As the lever arm rotates, the seat provides a forward and upward force, assisting the subject to a standing position.

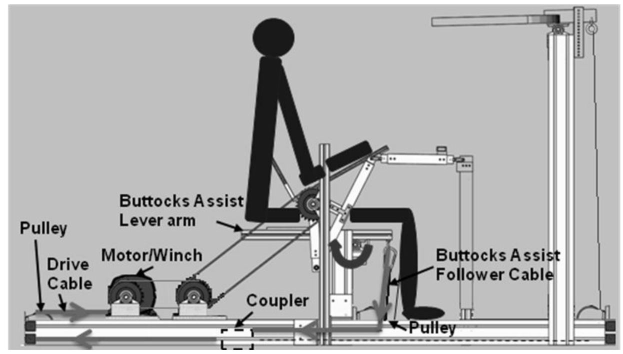

Figure 4: Buttocks Assist Configuration

Sensors and Actuators

The test bed is actuated by a Bison ¼ HP DC parallel shaft gear motor coupled to a cable driven mechanism for the buttocks and waist assists, and to a gear and linkage mechanism for the arm assist. The test bed has been designed to assist persons up to 90 kg and between 150 cm and 185 cm in height. Closed loop control of the motor has been implemented using a National Instruments PXI-7344 motion card and LabVIEW graphical user interface. The kinematics and dynamics of the user's STS motion are captured using four orientation sensors (Xsens) and a 6-axis AMTI force platform to measure the foot forces and Center of Pressure (CoP) respectively.

LOAD SHARING CONTROL SCHEME

The control scheme implemented in LabVIEW ensures load sharing between the user and the assist for the buttocks and waist assist modes. A conventional position controller, which drives the assist at a constant velocity once triggered by the user, is augmented by a real-time knee torque monitor to ensure that the assist will only be active while the user is applying knee torque during the motion.

The knee torque monitor uses anthropometric measurements and inputs from the force plate and body segment orientation sensors to compute a real-time estimate of the knee torque as the user rises. Knee torque is obtained by recursively applying the Newton-

Euler equations to a three-link biomechanical model, starting at the feet [10]. The force plate inputs (*CoP, F_{yfp}, F_{zfp}*) are used to calculate the ankle torque and forces according to Equations 1 and 2. The knee torque is computed using Equation 3.

$$T_{ankle} = -(m_{foot} * g * l_{foot}) + (CoP * F_{zfp}) - (h_{ankle} * F_{yfp}) \quad (1)$$
$$F_{yankle} = F_{yfp} \qquad F_{zankle} = F_{zfp} - m_{foot}g \quad (2)$$
$$T_{knee} = (L_d * F_a) + (l_p * F_s) + T_a - I_s\alpha_s \quad (3)$$

The user first stands without assistance and the torque monitor computes unassisted knee torque as a function of knee angle, generating a reference curve for subsequent use. As the user rises with assistance, the actual knee torque is computed in real time at 50 Hz and compared to the reference unassisted knee torque at the corresponding angle. If the subject generates less than 35% of the required knee torque for standing, the motor holds the current position, only continuing in the assist when the user applies knee torque above this level. The tuneable 35% limit is loosely based on Hughes [11] who found that young adults use approximately 35% of their maximum available torque for standing.

PRELIMINARY EXPERIMENT

Pilot experiments with the STS test bed were conducted on one healthy male subject. The assisted rises were evaluated to investigate the following questions:
a. How closely does the trajectory produced by each assist match a standard MT trajectory?
b. How does stability at seat-off and standing differ between assisted and unassisted STS?
c. What is the effect of the assists on reducing the strength required during assisted STS?

Anthropometric measurements were obtained and orientation sensors were attached to the shank, thigh and chest of the subject at the approximate center-of-mass (CoM) of each body segment. The subject performed five trials without assistance using a MT rise strategy, as described by [9]. Then the subject performed five STS trials in each of the three assist methods. Kinematic and force data was collected for each motion and used in the 3-link biomechanical model to compute total body kinematics and dynamics.

RESULTS

The data obtained was evaluated using metrics obtained from the literature. An MT rise strategy was characterized by a fast rise time (RT) and by a transition from horizontal to vertical CoM linear momentum at seat-off (HLM-VLM_{so}) [12]. Adherence to the MT rise strategy was determined by comparing the similarity of the RT and HLM-VLM_{so} of the assisted rises to the unassisted MT rise. The gravity moment arm, defined as the distance from the horizontal projection of the CoM to the CoP, was used as a measure of stability at seat-off (Y_{com}- CoP_{so}) [13] and the maximum trunk sway velocity (MTSV) was used to measure stability at the end of the stand [14]. Strength measures were the peak knee torque during each motion (Tk_{max}) [11] and the net joint work (W_{knee}), defined as the integral of the joint power curve, obtained by multiplying the joint moment with the joint angular velocity [15].

Table 1 shows a summary of these measures obtained from the model for each of the four STS rises. Figure 5 shows the trajectories of knee torque for each of the STS transfers. Comparisons were made between assisted and unassisted STS tasks (Table 1) to answer the three questions posed to investigate trajectory, stability, and torque effects.

All of the assisted transfers had rise times larger than the unassisted MT rise and CoM linear momentum differences at seat-off smaller than the unassisted MT rise. This indicates that none of the assists promoted a true MT rise strategy (Table 1).

The gravity moment arm at seat-off was reduced for all of the assists, indicating that the assisted transfers had greater stability at seat-off than the unassisted rise. Peak trunk sway velocity remained the same for the arm and buttocks assists but increased for the waist assist, indicating that there was less stability at standing for the waist-assist transfer (Table 1).

The peak knee torque was reduced for the waist and buttocks assisted transfers, indicating that these were effective in reducing the maximum knee load during the transfer. However, the knee torque remains close to peak value for a greater duration in the buttocks and arm assisted transfers (Figure 5); thus, the work required in these modes is not reduced (Table 1).

Table 1: Kinematic measures during STS motion

	Unassisted	Arm Assist	Waist Assist	Buttocks Assist
RT[a] (s)	2.05 (0.16) [d]	3.10 (0.08)	4.36 (0.54)	4.39 (1.03)
HLM-VLM$_{so}$ (m/s)[b] [%BW]	0.27 (0.03)	0.08 (0.04)	-0.05 (0.09)	0.14 (0.07)
Y_{com}- CoP_{so} [b] (cm)	13.6 (0.8)	9.5 (0.6)	4.3 (1.1)	7.5 (1.8)
MTSV[c] (rad/s)	0.15 (0.05)	0.11 (0.03)	0.60 (0.33)	0.13 (0.06)
Tk_{max}[%BwxBH]	1.02 (0.03)	1.03 (0.05)	0.85 (0.07)	0.89 (0.07)
W_{knee} [J/Kg]	1.65 (0.1)	1.75 (0.1)	1.25 (0.2)	1.65 (0.1)

[a]Rise time defined from start of hip flexion to full extension of thigh.
[b]Seat-off is defined as the point at which the buttocks leaves the chair for the unassisted and arm assisted rise and as the point at which the subject loses contact with assist mechanism for the waist and buttocks assisted rise.
[c]Trunk sway velocity is measured during the stabilization phase of the stand, after the subject has reached a fully erect position.
[d]Five trials for each STS mode of rise, results reported as means (standard deviation)

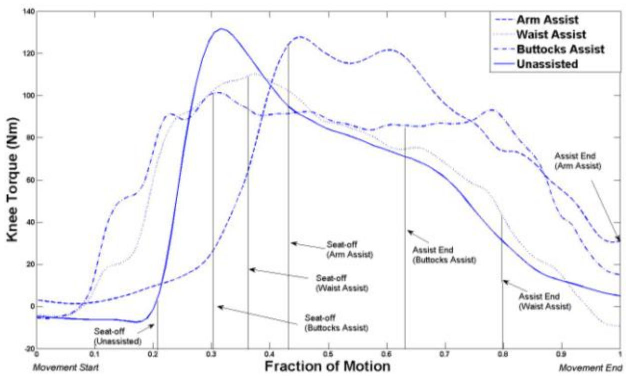

Figure 5: Representative knee torque trajectories for four methods of STS transfer

DISCUSSION & CONCLUSIONS

In this paper we presented the design of a Sit-to-Stand assistive test bed and preliminary experiments with one subject. The test bed allows for the investigation of assisted STS with assistance provided at the arms, waist, and buttocks. Preliminary experiments have shown that all of the methods of assist increase the stability of the user, and the peak knee torque is reduced for the waist and buttocks assisted transfers. The increase in stability during the arm assisted transfer is consistent with results from experimental analysis of a similar STS arm assist mechanism investigated by Médéric [2]. The increase in stability and knee torque reduction during the buttocks assisted transfer is in agreement with results from a kinematic and kinetic analysis of ejector chair assisted STS by Munroe [3]. Future work will focus on the redesign of the control scheme to promote a true MT-type transfer and reduce the work required to stand for all of the assist methods. [i]

REFERENCES

[1] G. Hendershot and J. Fulton, with Dawson D., *Aging in the Eighties Functional Lim. of Individuals Age 65 Years and Over*, Public Health Service, Hyattsville, MD: 1987.

[2] P. Médéric, V. Pasqui, F. Plumet, and P. Bidaud, "Elderly People Sit to Stand Experimental Analysis," *Proc. of the 8th International Conference on Climbing and Walking Robots (CLAWAR 2005)*, pp. 953-960.

[3] B. Munro, "A kinematic and kinetic analysis of the sit-to-stand transfer using an ejector chair implications for elderly rheumatoid arthritic patients," *Journal of Biomechanics*, vol. 31, Dec. 1997, pp. 263-271.

[4] Technology for Long Term Care - Lifting & Transferring: www.techforltc.org/producttype.aspx?id=2057,1982

[5] D.K. Weiner, R. Long, M.A. Hughes, J. Chandler, and S. Studenski, "When older adults face the chair-rise challenge. A study of chair height availability and height-modified chair-rise performance in the elderly," *J. of the American Geriatrics Society*, vol. 41, Jan. 1993, pp. 6-10.

[6] M. Hirvensalo, T. Rantanen, and E. Heikkinen, "Mobility difficulties and physical activity as predictors of mortality and loss of independence in the community-living older population," *Journal of the American Geriatrics Society*, vol. 48, pp. 493-498.

[7] D. Chugo, T. Kitamura, J. Songmin, and K. Takase, "Steady standing assistance using active walker function," *SICE Annual Conference 2007*, IEEE, 2007, pp. 3060-3063.

[8] D. Chugo, H. Kaetsu, N. Miyake, K. Kawabata, H. Asama, and K. Kosuge, "Force assistance system for standing-up motion," *2006 Int. Conf. on Mechatronics and Automation*, IEEE, 2006, pp. 1103-1108.

[9] D.M. Scarborough, C.A. McGibbon, and D.E. Krebs, "Chair rise strategies in older adults with functional limitations." *Journal of rehabilitation research and development*, vol. 44, Jan. 2007, pp. 33-42.

[10] E.B. Hutchinson, P.O. Riley, and D.E. Krebs, "A dynamic analysis of the joint forces and torques during rising from a chair," *IEEE Trans. on Rehabilitation Engineering*, vol. 2, Jun. 1994, pp. 49-56.

[11] M.A. Hughes, B.S. Myers, and M.L. Schenkman, "The role of strength in rising from a chair in the functionally impaired elderly," *Journal of Biomechanics*, vol. 29, Dec. 1996, pp. 1509-1513.

[12] P.O. Riley, M.L. Schenkman, R.W. Mann, and W.A. Hodge, "Mechanics of a constrained chair-rise," *Journal of biomechanics*, vol. 24, Jan. 1991, pp. 77-85.

[13] F. Bahrami, "Biomechanical analysis of sit-to-stand transfer in healthy and paraplegic subjects," *Clinical Biomechanics*, vol. 15, Feb. 2000, pp. 123-133.

[14] J. Gill, J.H.J. Allum, M.G. Carpenter, M. Held-Ziolkowska, A.L. Adkin, F. Honegger, and K. Pierchala, "Trunk sway measures of postural stability during clinical balance tests: effects of age," *J Gerontol A Biol Sci Med Sci*, vol. 56, 2001, pp. M438-447.

[15] P. Wretenberg and U.P. Arborelius, "Power and work produced in different leg muscle groups when rising from a chair," *European J. of Applied Physiology and Occupational Physiology*, vol. 68, 1994, pp. 413-417.

[i] This work was supported in part by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Institute for Computing, Information and Cognitive Systems (ICICS) at UBC.