2018

Asymmetry After Hip Fracture: A Multi-factorial Problem

Andrew J. Meszaros
George Fox University, ameszaros@georgefox.edu

Cindy Zablotny
George Fox University, czablotny@georgefox.edu

Paul A. Shew
George Fox University, pshew@georgefox.edu

Bret Reordan

Asymmetry After Hip Fracture: A Multi-factorial Problem

Andrew Meszaros, PT, PhD[1]
Cynthia Zablotny, PT, DPT, NCS[1]
Paul Shew, PT, DPT[1]
Bret Reordan, PT, DPT[2]

[1]*George Fox University, Newberg, OR*
[2]*Therapeutic Associates, Salem, OR*

ABSTRACT

Background and Purpose: Sit-to-stand (STS) and static standing mechanics are related to fall risk and function after hip fracture. Often, these patients avoid weight bearing on the fracture side after rehabilitation. The purpose of this study was to use a novel clinically-relevant protocol to examine standing and STS vertical ground reaction force (vGRF) in light of perceptual measures of loading symmetry and muscle torque production in this population. **Methods:** A person post hip fracture performed 3 different STS conditions and 2 simple load-matching tasks. Motion, force plate, and perceptual data on weight distribution and load were collected. **Findings:** Standing and STS asymmetry were not explained by strength. A perceptual issue may be limiting performance progress in achieving symmetry. **Clinical Relevance:** Active task-specific training, augmented by attention to perception of movement, load, or strength, may assist in attaining symmetry in STS. **Conclusion:** Some patients may benefit when mechanical and perceptual performances are considered together.

Key Words: sit-to-stand, center-of-mass, loading, perception

BACKGROUND

Physical therapy practitioners working across many different practice settings are acutely aware of the significant public health issues resulting from the onset of a hip fracture and its sequelae. It has been estimated that on a worldwide basis, hip fracture impacts 1.6 million people annually; the majority are female.[1] Of those who sustain a hip fracture, approximately 18% to 30% will die within the first year post onset.[2,3] More than half of these individuals will fall at least one time in the year following initial fracture, and 28% will sustain more than one fall within this timeframe.[4] Nineteen percent will fall while moving from sit-to-stand (STS) or sit to walk.[5]

Activity-based Limitations

Activity-based limitations have been studied extensively.[3,6-8] Following fracture, approximately 34% to 59% of individuals will resume their pre-fracture basic activities of daily living (ADLs) function by 3 months, with this proportion increasing to 42% to 71% at 6 months.[6] In one prospective study of older adults followed pre- and post-fracture, the functional declines noted across time were 3 times larger in those who went on to fracture, compared to the non-fracture group.[9] An inability to attain pre-fracture functional status has been clearly evident in activities involving the use of the lower extremities, and this has led to new levels of dependency after fracture onset.[7] When individuals considered independent with basic mobility skills before fracture are assessed one year after this event, half will require assistance when rising from an armless chair or attempting to walk one block, more than two-thirds will need help with toileting and bathing transfers, and 90% will need help when climbing stairs. These values for dependency in lower extremity functional task completion do not improve significantly at the 2-year post-fracture mark.[7]

Sit-to-Stand Variables Following Hip Fracture

One of the lower extremity tasks that has been studied extensively in older adults and in those recovering from hip fracture is the STS transition.[3,10-15] This transition forms a necessary link to achieving independence in a wide variety of self-care and mobility-based ADLs. Even in those individuals who achieve an independent status in rising from STS post-hip fracture, research has shown that altered movement strategies are frequently adopted.[11-15] These movement modifications are initiated in the preparation phase of the STS transition, which begins before the buttocks are lifted from the support surface, and continue into the rising phase, which begins at the time of seat-off. Studies have shown that during the preparation phase, the rate of force development under the involved limb is 42% lower than the uninvolved limb.[11-13] Kneiss et al[13] report that during the rising phase of the transition, significantly lower peak involved side vertical ground reaction force (vGRF) has also been recorded, with reductions of 27% compared to the non-fractured side. Significantly lower peak hip and knee moments and powers have been recorded on the involved side also, when compared to the non-fractured limb. To insure continued independence in rising, compensations for this involved side force reduction are routinely made, and include a reduction in the speed of rising, coupled with a strong reliance on uninvolved side knee extensor moments and powers.

By manipulating initial STS task constraints and difficulty, researchers have gained significant insight into the movement strategies used to rise following hip fracture. This has been accomplished by asking subjects to rise independently with and without arm use.[12] When upper extremity use was permitted, individuals post-hip fracture demonstrated a significantly higher arm impulse, compared to non-fractured control subjects.[12] Despite this representing an easier task overall, arm use did not significantly diminish the preferential reliance on the uninvolved lower extremity. An asymmetric movement pattern persisted, with a lower rate of force development noted on the involved side during the STS preparation phase and a reduced vGRF measured during the rising phase. However, when required to perform a STS transition without arm use, these same individuals post-hip fracture demonstrated an ability to increase their involved side vGRF and rate of force development to a more reasonably functional level, yet still preferentially depended on the uninvolved limb's force production to rise. These findings suggest that the involved limb had the capacity to contribute in a more symmetric manner to the task of rising, and that it was capable of generating greater vGRF when a higher demand for use was imposed on it. The fact that an asymmetric movement strategy persisted, regardless of task difficulty, supports the concept that a pattern of learned non-use had been adopted by these individuals.

Achieving functional independence in transitioning from STS represents an important milestone in the rehabilitation of an individual post-hip fracture. However, it is possible that an emphasis on function over movement strategy may have a detrimental effect on the involved limb's ability to realize its maximal force-generating capacity during rising. Furthermore, physical therapists themselves lack accuracy in judging the magnitude of the involved limb's peak vGRF during rising, and this may limit how much emphasis is placed on remediating this learned non-use strategy. In a recent study of home health physical therapists who viewed videotapes of subject's post-hip fracture independently rising from STS, judgments of the involved limb's vGRF were made with a mean accuracy of just 39%.[16]

Implications of Sit-to-Stand Asymmetry Variables

To further understand the asymmetric STS movement pattern seen following hip fracture, investigators have sought to explain its value as a clinical finding.[11,13-15] Asymmetries in the involved limb's rate of force development during STS have been shown to have strong correlations with performance on the Berg Balance Scale (r = 0.80) and with gait speed (r = 0.81), while the peak vGRF of the involved limb also correlates well with gait speed (r = .72).[13] Sit-to-stand force asymmetry following hip fracture has also been shown to play a significant role in explaining performance on a timed stair climb test and that it may assist physical therapists in making accurate predictions of function in high level upright tasks, such as stair climbing, which rely on unilateral strength and control.[14] Moderate to high correlations have also been demonstrated between lower extremity symmetry measurements of muscle function (strength and power) and vGRF symmetry in STS (r= 0.58-0.76).[15]

Training Efforts to Reduce Sit-to-Stand Asymmetry

Although many investigations have provided insight into the magnitude of STS asymmetry following hip fracture, few have specifically addressed its clinical management. Briggs and co-workers[15] recently completed a longitudinal study to address asymmetry using multimodal training with activities such as high intensity strengthening, task specific training, and balance and gait training. An emphasis was placed on rising symmetry and regaining confidence during training. This intervention resulted in significantly greater symmetry of lower extremity vGRF variables during STS and improved knee extension strength and power on the involved limbs. Despite the rigors of this program and the gains that were realized, the asymmetry of specific STS variables and of muscle performance tests that remained post-training exceeded those that were previously measured in healthy older adults.[11,13,15] These findings may suggest that there may be another factor contributing to the asymmetry that was not addressed by this multimodal intervention approach.

Perception

Although significantly different etiologies prevail, the asymmetric rising patterns and learned non-use strategy noted following hip fracture have similar characteristics to that seen following stroke.[17] The nature of stroke, with its multiple body system involvement, has led investigators to consider the contributions of factors such as muscle strength and activation, sensation, and perception as some of the possible contributing factors to the pattern of asymmetric rising.[17] Different aspects of perception have been considered in research involving those with stroke, including perceptions of weight bearing load or force, level of effort, and verticality. In contrast, research involving those recovering from hip fracture revolves mainly around the musculoskeletal factors that interact, since this body system is clearly compromised in this situation. It is possible, however, that even in this population of patients, the motor strategies that emerge in STS transitions are dependent on the contributions of other body systems and functions, such as perception. To date, however, the concept of perceptual deficits contributing to asymmetry following hip fracture has not yet been explored.

CASE DESCRIPTION

The following patient was recruited as part of a larger ongoing study that seeks to identify the various mechanisms behind chronically asymmetric left/right loading during STS. There are several hypotheses: (1) Strength deficits will not fully account for loading asymmetries in some fully-rehabilitated patient's post-hip fracture. (2) These patients will not be able to accurately perceive their loading asymmetry, nor spontaneously fix it. (3) Asymmetric individuals will use perceived sense of effort, rather than actual sense of force, to determine load distribution through the feet.

This subject is a 74-year-old female who sustained a hip fracture of her dominant leg following a fall that was managed surgically with total joint arthroplasty. Beyond a mild postsurgical infection, the subject's rehabilitation was unremarkable; her health was otherwise stable. She successfully completed a standard course of physical therapy, and was tested in our motion analysis laboratory 6 months after surgery. She was able to rise from a standard height chair without using arms, to walk independently in the community, and attend a one-hour exercise class 3 times weekly. No sensory deficits existed.

METHODS

The broad goal was to integrate STS motor performance data with measures of strength, perceived effort of difficulty, perceived load, and perceived load distribution through the feet. Kinematic motion was analyzed using a Qualysis 3D system (10 cameras, 100Hz rate, 6Hz Butterworth filter) with two AMTI force plates (1,000 Hz), C-Motion Visual3D (with Dempster Hanavan for COM) and DataGraph software (Visual Data Tools Inc.). There were 3 STS conditions: (1) natural "self-selected," (2) a "50/50 fix" trial in which the subject was given feedback on her prior "self-selected" symmetry performance and then encouraged to concentrate on equal left-right weight distribution during another STS bout, and (3) "maximal excursion" STS trials in which the subject was asked to place as much weight as possible through one leg, without falling, while rising to stand (Figure 1). For STS, the subject was seated on a custom-built platform (armless and backless) that was adjusted to achieve the following start position: hip flexion 90°, thigh level with floor, feet even at shoulder's width, self-selected natural knee/ankle (up to 15° ankle dorsiflexion), and hands positioned with palms touching ("prayer position").

Perception during STS was assessed using a custom-built Visual Analog Scale (VAS) device. Immediately after each STS bout, the subject was asked to move a sliding marker from a centered position toward either the left or right (up to 3 inches each) to reflect the magnitude of her perceived left-right weight distribution during the rising (Figure 2). The experimenter then recorded marker position from a digital display (ie, 70/30).

Isometric knee extensor maximal strength was tested bilaterally in sitting, at 90°, with a load cell at each distal tibia (Kistler Force Link 9311B at 1,000 Hz, low pass filtered at 10Hz, 49.99 N/v). With this same arrangement, a force matching task was used to assess the individual's accuracy in perceiving submaximal muscle torque production. The subject was asked to generate a self-selected isometric knee extension torque on one side, then rest, then replicate the exact same torque on the contralateral side. The matching was performed twice, with the fractured and non-fractured limbs each having the opportunity to serve as the referenced standard for the other. The subject did not numerically assign a VAS estimate to the torque, because low efforts are difficult to meaningfully rate without a submaximal reference.

A matching task was also used to assess loading perception through the feet. From a static standing position, the subject was asked to shift a self-selected amount of weight toward one side, return to upright neutral, and then replicate the exact same load on the contralateral side (Figure 3). This was done twice, with each leg serving as the referenced standard. Immediately after each trial, the subject used the VAS device to offer her quantitative perception of the chosen load distribution through the feet (ie, 60/40).

FINDINGS

The subject had equal knee extensor muscle strength, with only 0.3% body weight (BW) difference between legs (Table 1). The accuracy of her extensor torque perception is excellent, with a small matching over-estimate of target torques by approximately 2% BW; this existed no matter which lower extremity served as the standard. This evidence suggests that neither knee extensor muscle weakness nor muscle torque perception account for asymmetries in sit-to-stand and matching tasks while standing.

During self-selected STS, the subject avoided loading the fracture leg, resulting in a vGRF asymmetry of approximately 12% (Table 2; Figure 4*). The subject sensed that she was asymmetric. Her VAS perceptual load rating was excellent in the non-fracture leg for both the STS and static standing tasks (within 3-5%); loading perception for the fractured leg was more accurate for the static standing task (4% error) than the STS task (13% error) (Table 2). After the actual magnitude of left-right vGRF asymmetry was disclosed to the subject as summary feedback, she was able to minimize the left-right difference to approximately 2% BW. To achieve this improvement, the subject's strategy was to pre-load the fracture-side's foot prior to standing, while still sitting (Figure 4+). She also successfully moved the center-of-mass closer to midline during STS (Figure 5+). However, during static standing, after the rise was complete, she was unable to maintain the center of mass (COM) at midline (Figure 5++).

During static standing, the subject had a significant load distribution asymmetry between the fractured side (31% BW) and non-fractured side (68% BW) (Table 2; Figure 4**). This 37% difference was reduced to 11% after summary feedback was given (Figure 4++).

The STS maximal excursion tests revealed a large difference in motor performance

Figure 1. Subject performing right side maximal excursion during a sit-to-stand maneuver. See also Figure 6.

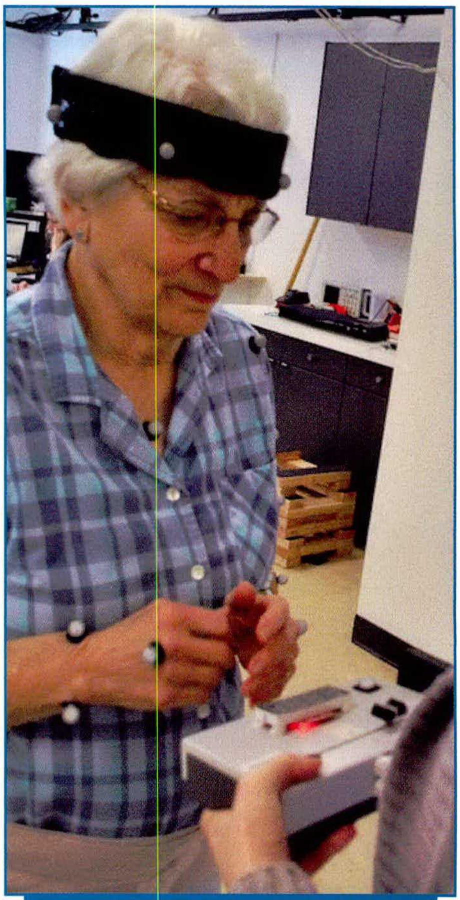

Figure 2. Subject offering an estimate of her left-right sit-to-stand loading symmetry, using a custom-built digital visual analog scale device.

between the left and right sides (Figure 1). The COM excursion from midline was 32% less on the fracture side (not shown). The non-fracture side accepted 27% more BW than the fracture side (Table 2; Figure 6*) despite the two sides having nearly equal knee extensor strength. The subject's VAS score suggests that she had an accurate perception of this difference during maximal load. As observed earlier, the subject's strategy to improve STS weight bearing on the fracture side was by pre-loading it in sitting, prior to rising (Figure 6+). Interestingly, after the subject was required to bear that large load on the fracture side during STS, she showed nearly perfect symmetry in static standing (48/50, Table 2; Figure 6++).

The VAS perceptual ratings of the magnitude of a standing lateral shift were quite accurate for both the fracture and non-fracture sides (5-7%), (Table 3; Figure 3). Based upon this, one might expect the subject to be highly accurate at matching loads between sides. Interestingly, this was not the case. The subject had a persistent residual mismatch of approximately 20% BW that seemed to be embedded in the fracture side (Table 3). When the fractured leg was used to produce the referenced standard, the match target was over-shot by 18% (Figure 7**). When the fracture leg was used to produce the match, it was under-shot by 22%. Similarly, COM excursion was reduced by approximately 17% when the fracture side set the standard for matching (Figure 8). A contributing factor to the poor matching could have been the asymmetric vGRF loading observed during quiet standing, at the start of each matching task.

CLINICAL RELEVANCE

In summary, these findings offer support to the clinically important concept that strength deficits alone do not fully explain loading asymmetry after hip fracture.[15] Despite our subject's ability to accurately perceive movement and torque limitations, she was still unable to spontaneously correct loading asymmetries without being given quantified summary feedback prior to prac-

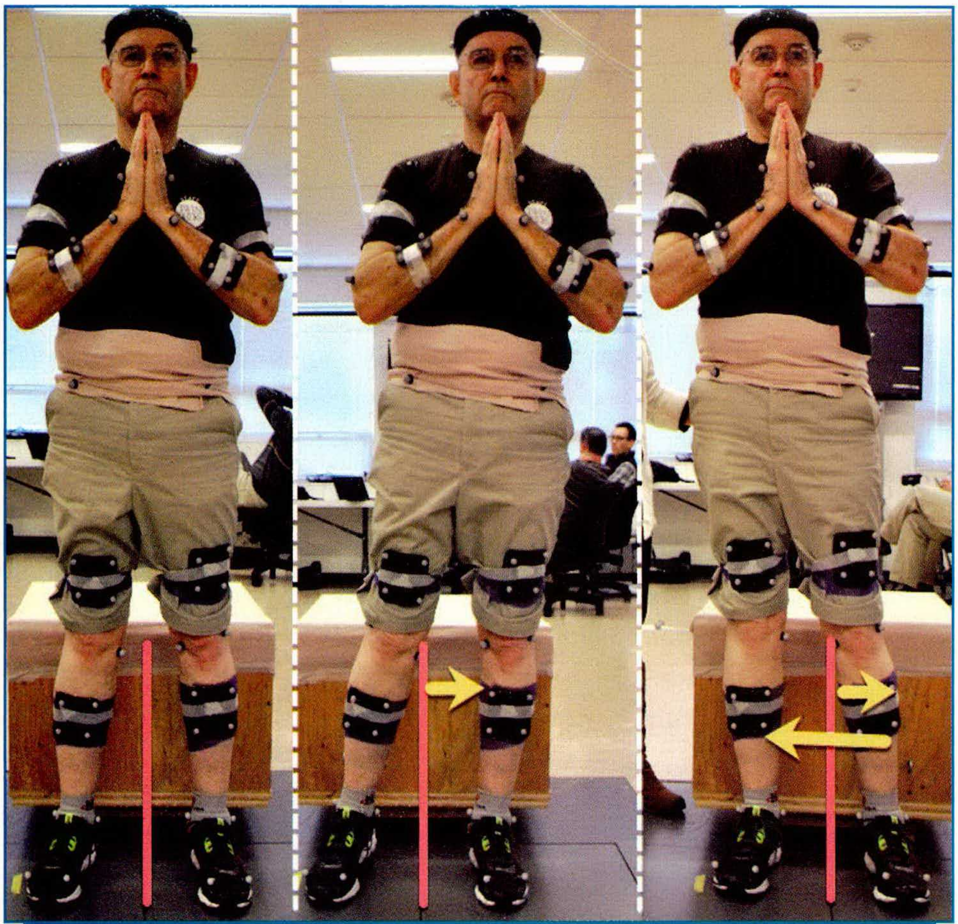

Figure 3. Example of a subject performing the lateral weight-shift matching task. In this case, after the person loaded his left side, he attempted to replicate the exact same load on the right side. See also Figures 7 and 8.

ticing the task. That practice likely required her to make complex perceptual adjustments to recalibrate senses of effort and force. Maximal weight bearing on the fractured side during STS led to improvements in vGRF symmetry during STS and static standing. Matching tasks may be a useful clinical tool for addressing loading symmetry.

Limitations

The results of this case are limited by several factors due to the study design. The findings are not generalizable, based upon a single subject. We chose "strength" to be represented by isometric knee extension torque. However, other muscles also contribute to COM control during STS. For example, during the middle "transition" phase of STS, biceps femoris and gluteus maximus have been shown to play a key role.[18] During matching tasks, we allowed the subject to self-select her own load or excursion. However, it may be that perceptual estimates are magnitude sensitive. For example, it may be easier to perceive symmetry differences at 80/20 (left/right) than at 65/35. Finally, our paradigm addressed motor performance and not motor learning.

CONCLUSIONS

In the rehabilitation of an individual post-hip fracture, there is potential clinical benefit to be found in the integration of standard motion and force data with data from perceptual-heavy tasks such as VAS rating, load matching during weight bearing, torque matching during isometrics, and maximal excursion during STS.

REFERENCES

1. International Osteoporosis Foundation. Facts and statistics—Hip Fracture. www.iofbonehealth.org/facts-statistics. Accessed June 15, 2018.
2. Brauer CA, Coca-Perraillon M, Cutler DM, Rosen AB. Incidence and mortality of hip fractures in the United States. *JAMA*. 2009;302(14):1573-1579. doi: 10.1001/jama.2009.1462.
3. Magaziner J, Fredman L, Hawkes W, et al. Changes in functional status attributable to hip fracture: a comparison of hip fracture patients to community-dwelling aged. *Am J Epidemiol.* 2003;157(11):1023-1031.
4. Lloyd BD, Williamson DA, Singh NA, et al. Recurrent and injurious falls in the year following hip fracture: a prospective study of incidence and risk factors from the sarcopenia and hip fracture study. *J Gerontol A Biol Sci Med Sci*. 2009;64(5):599-609. doi: 10.1093/gerona/glp003. Epub 2009 Mar 5.

Table 1. Summary of Isometric Knee Extension Torque

	KE force (mean %BW)			VAS rating of KE force (% max)	
Lower Extremity:	ok	fx	Δ	ok	fx
TASK					
KE MVIC:	17.9	17.6	0.3	(100)	(100)
Match a self-selected KE using…					
…fx-side as the standard:	12.8	10.6	over-shot by 2.2	-	-
…ok-side as the standard:	8.6	10.9	over-shot by 2.3	-	-

Abbreviations: KE, knee extension; BW, body weight; VAS, visual analog scale; max, maximum; fx, fracture; ok, non-fractured; Δ, difference between legs; MVIC, maximum voluntary isometric contraction.

Table 2. Summary of Sit-to-Stand With Perceptual Ratings

lower extremity:	VAS rating of STS loading (% max)		Actual STS peak vGRF (%BW)		Actual vGRF of static standing, after rising (mean %BW)	
	ok	fx	ok	fx	ok	fx
TASK						
STS self-selected:	65	35	60[4] (* green)	48[4] (*red)	68[4] (**green)	31[4] (**red)
STS trying 50/50 fix:	(50)	(50)	53[4]	55[4]	55[4] (++green)	44[4] (++red)
STS max excursion to…						
… side with the ok LE:	80	20	87[6]	37[6]	66[6]	33[6]
… side with the fx LE:	40	60	38[6]	60[6]	48[6]	50[6]

Abbreviations: VAS, visual analog scale; STS, sit-to-stand; vGRF, vertical ground reaction force; max, maximum; BW, body weight; fx, fracture; ok, non-fractured; LE, lower extremity;

Key: * green = see the * icon near the figure's green line; superscript [6] = see Figure 6

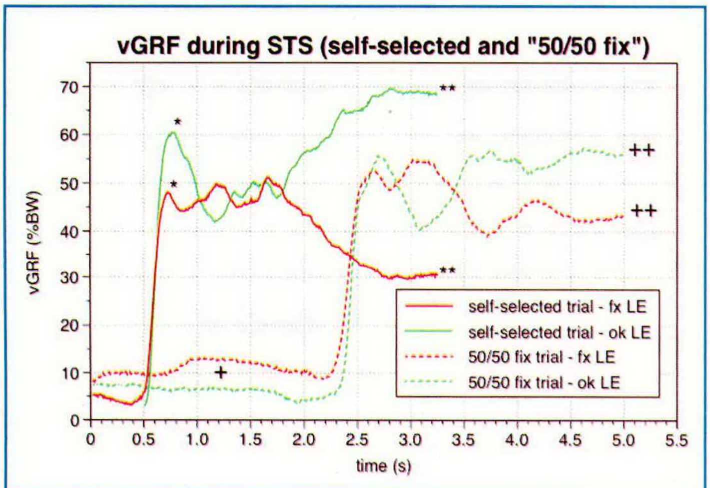

Figure 4. Vertical ground reaction force data for two discontinuous sit-to-stand trials: (1) solid lines = natural self-selected weight distribution; (2) hatched lines = after feedback, when the subject was focused on STS symmetry. Red = fractured leg. Green = non-fractured leg. See also Table 2, Figure 5.

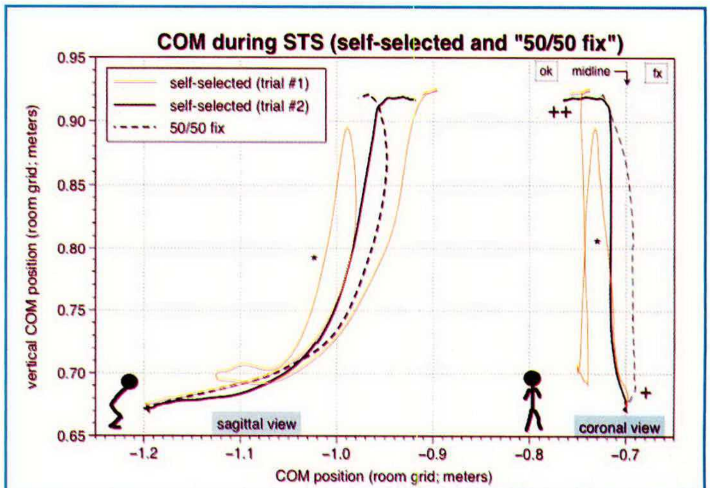

Figure 5. Center of mass data for three sit-to-stand trials. Orange = first natural self-selected trial, with the subject nearly unsuccessful. Black solid = second natural self-selected trial. Black hatched = after summary feedback was offered, with encouragement to fix asymmetries and rise with a 50/50 distribution. See also Figure 4.

5. Leavy B, Byberg L, Michaelsson K, Melhus H, Aberg AC. The fall descriptions and health characteristics of older adults with hip fracture: a mixed methods study. *BMC Geriatr*. 2015;15:40. doi: 10.1186/s12877-015-0036-x.
6. Dyer SM, Crotty M, Fairhall N, et al. A critical review of the long-term disability outcomes following hip fracture. *BMC Geriatr*. 2016;16:158. doi: 10.1186/s12877-016-0332-0.
7. Magaziner J, Hawkes W, Hebel JR, et al. Recovery from hip fracture in eight areas of function. *J Gerontol A Biol Sci Med Sci*. 2000;55(9):M498–M507.
8. Mangione KK, Palombaro KM. Exercise prescription for a patient 3 months after hip fracture. *Phys Ther*. 2005;85(7):676-687.
9. Bentler SE, Liu L, Obrizan M, et al. The aftermath of hip fracture: discharge placement, functional status change, and mortality. *Am J Epidemiol*. 2009;170(10):1290-1299. doi: 10.1093/aje/kwp266. Epub 2009 Oct 4.
10. Schot PK, Knutzen KM, Poole SM, Mrotek LA. Sit-to-stand performance of older adults following strength training. *Res Q Exerc Sport*. 2003;74(1):1-8.
11. 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 (Bristol, Avon)*. 2011;26(5):470-476. doi: 10.1016/j.clinbiomech.2010.12.004. Epub 2010 Dec 31.
12. Kneiss JA, Houck JR, Bukata SV, Puzas JE. Influence of upper extremity assistance on lower extremity force application symmetry in individuals post-hip fracture during the sit-to-stand task.

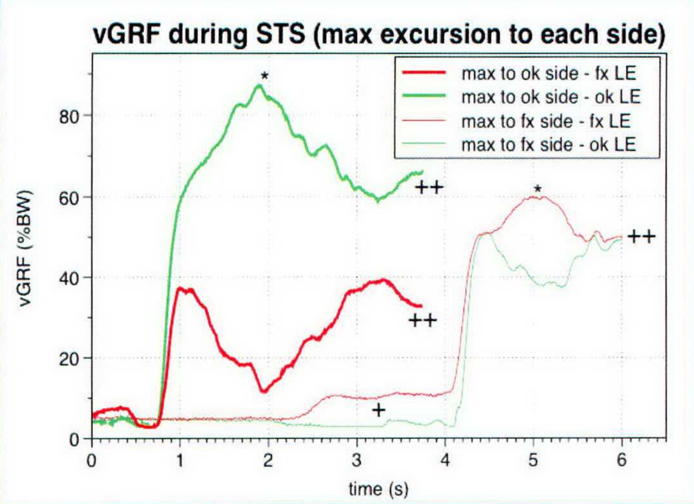

Figure 6. Vertical ground reaction force data for two discontinuous sit-to-stand trials: (1) thick lines = maximal excursion to the non-fractured "ok" side, (2) thin lines = maximal excursion to the fractured side. Red = fractured leg. Green = non-fractured leg. See also Table 2, Figure 1.

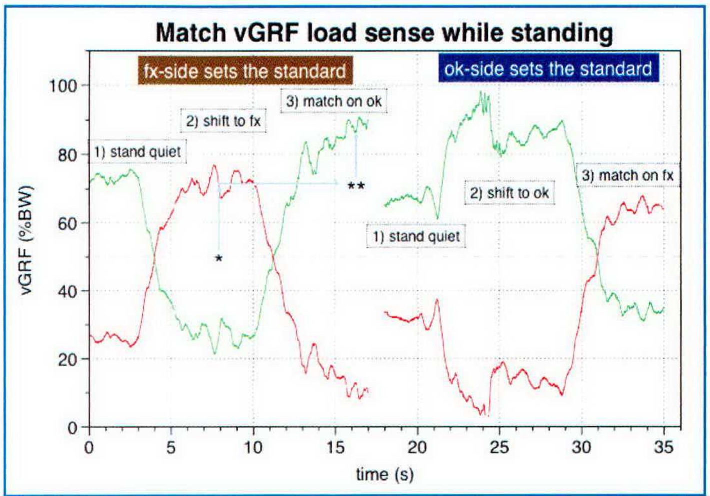

Figure 7. Vertical ground reaction force data for two discontinuous trials of matching lateral load shifts in standing. The subject was asked to stand quietly, shift weight to one side (the standard), then replicate that load on the contralateral side (the match). (1) brown half = when the fractured leg served as the reference standard; (2) blue half = when the non-fractured "ok" leg was the reference standard. Red = fractured leg. Green = non-fractured leg. See also Table 3, Figures 3, 8.

Table 3. Summary of Matching Trials With Perceptual Ratings

TASK	vGRF of initial shift (%BW)	vGRF of shift match %BW)	success of vGRF match (%BW)	VAS rating of shift match (% max)
Match a self-selected standing lateral shift when using…				
…fx-side as standard: (midline change)	71[7] (+21) (*)	89[7] (+39) (**)	over-shot by 18%	84 (+34)
…ok-side as standard: (midline change)	87 (+37)	65 (+15)	under-shot by 22%	72 (+22)

Abbreviations: vGRF, vertical ground reaction force; VAS, visual analog scale; BW, body weight; max, maximum; fx, fracture; ok, non-fractured

Key: * = see the * icon in the figure; [7] = see Figure 7.

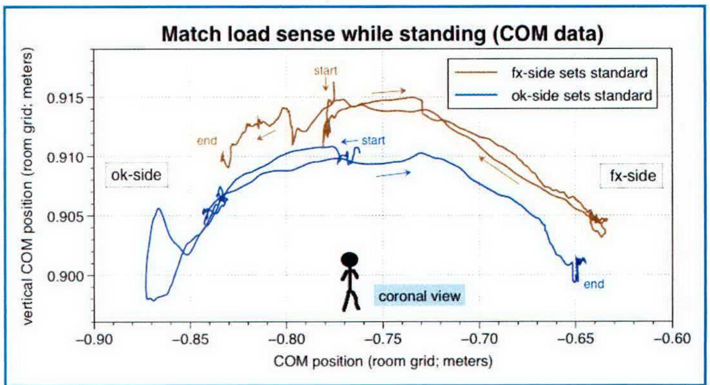

Figure 8. Center of mass data for two standing matching trials. The subject was asked to stand quietly, shift weight to one side (the standard), then replicate that load on the contralateral side (the match). (1) brown = when the fractured leg served as the reference standard; (2) blue = when the non-fractured "ok" leg was the reference standard. See also Figures 3, 7.

J Orthop Sports Phys Ther. 2012;42(5):474-481. doi: 10.2519/jospt.2012.3562. Epub 2012 Apr 30.

13. Kneiss JA, Hilton TN, Tome J, Houck JR. Weight-bearing asymmetry in individuals post-hip fracture during the sit to stand task. *Clin Biomech (Bristol, Avon).* 2015;30(1):14-21. doi: 10.1016/j.clinbiomech.2014.11.012. Epub 2014 Nov 29.
14. Briggs RA, Houck JR, Drummond MJ, Fritz JM, LaStayo PC, Marcus RL. Asymmetries identified in sit-to-stand task explain physical function after hip fracture. *J Geriatr Phys Ther.* 2017; doi: 10.1519/JPT.0000000000000122. [Epub ahead of print]
15. Briggs RA, Houck JR, LaStayo PC, Fritz JM, Drummond MJ, Marcus RL. High-intensity multimodal resistance training improves muscle function, symmetry during a sit-to-stand task, and physical function following hip fracture. *J Nutr Health Aging.* 2018;22(3):431-438. doi: /10.1007/s12603-017-0977-1.
16. Zablotny C, Hilton T, Riek L, Kneiss J, Tome J, Houck J. Validity of visual assessment of sit to stand after hip fracture. *J Geriatr Phys Ther.* 2018. doi: 10.1519/JPT.0000000000000197. [Epub ahead of print]
17. Boukadida M, 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(3):167-172. doi: 10.1016/j.rehab.2015.04.007. Epub 2015 May 23.
18. Millington PJ, Myklebust BM, Shames GM. Biomechanical analysis of the sit-to-stand motion in elderly persons. *Arch Phys Med Rehabil.* 1992;73(7):609-617.