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Influence of Upper Extremity Assistance on Lower Extremity Force Application Symmetry in Individuals Post–Hip Fracture During the Sit-to-Stand Task

More than 300 000 individuals over the age of 65 years are expected to sustain a hip fracture in the upcoming year in the United States.[1,16,17] With the increase in the number of elders, the management of hip fracture is expected to continue to require significant medical resources, accounting for 5 to 6 billion healthcare dollars per year.[5,16] After hip fracture, functional losses are greater than what would be expected in the normal aging process, particularly in individuals who are community dwelling.[8,11] Consequences of a hip fracture in community-dwelling elderly individuals include significant loss of physical function (greater than 50% loss of lower extremity function), increased risk of falls (within 6 months, 50% will fall again), and increased mortality rates (greater than 25% within a year).[11,16,25] A decrease in fall rates or improvements in function may decrease these costs and improve outcomes for individuals with hip fracture. For community-dwelling elderly, independence with functional activities is the goal of rehabilitative care.

STUDY DESIGN: Controlled laboratory study using a cross-sectional design.

OBJECTIVES: To compare lower extremity force applications during a sit-to-stand (STS) task with and without upper extremity assistance in older individuals post–hip fracture to those of age-matched controls.

BACKGROUND: A recent study documented the dependence on upper extremity assistance and the uninvolved lower limb during an STS task in individuals post–hip fracture. This study extends this work by examining the effect of upper extremity assistance on symmetry of lower extremity force applications.

METHODS: Twenty-eight community-dwelling elderly subjects, 14 who had recovered from a hip fracture and 14 controls, participated in the study. All participants were independent ambulators. Four force plates were used to determine lower extremity force applications during an STS task with and without upper extremity assistance. The summed vertical ground reaction forces (vGRFs) of both limbs were used to determine STS phases (preparation/rising). The lower extremity force applications were assessed statistically using analysis of variance models.

RESULTS: During the preparation phase, side-to-side symmetry of the rate of force development was significantly lower for the hip fracture group for both STS tasks ($P<.001$). During the rising phase, the vGRF impulse of the involved limb was significantly lower for the hip fracture group for both STS tasks ($P = .045$). The vGRF impulse for the uninvolved limb was significantly increased when participants with hip fracture did not use upper extremity assistance compared to elderly controls ($P = .002$). This resulted in a significantly lower vGRF symmetry for the hip fracture group during both STS tasks ($P<.001$).

CONCLUSION: Participants with hip fracture who were discharged from rehabilitative care demonstrated decreased side-to-side symmetry of lower extremity loading during an STS task, irrespective of whether upper extremity assistance was provided. These findings suggest that learned motor control strategies may influence movement patterns post–hip fracture. *J Orthop Sports Phys Ther 2012;42(5):474-481. doi:10.2519/jospt.2012.3562*

KEY WORDS: *biomechanics, chair, ground reaction forces*

Independence with the sit-to-stand (STS) task occurs late in the hip fracture recovery process, in part due to high load requirements of the hip and knee. For this reason, researchers have proposed the use of the STS task as an outcome measure to assess functional status.[9,16-18] When individuals lack adequate lower extremity strength or coordination, success during an STS task often occurs by

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increasing upper extremity assistance.[6,7] Another alteration to accomplish the STS task is to increase the contribution of the uninvolved limb, combined with increased upper extremity assistance.[22,26] To assess recovery post–hip fracture, there is a high reliance on clinical tests that focus on functional independence. Common clinical tests, however, only assess bilateral function. For example, clinical measures, such as the timed up-and-go test, are not designed to evaluate unilateral deficits and do not account for compensations such as increased reliance on the uninvolved limb.[17,25,27] Identifying unilateral compensation is important because of its association with sustained functional decline.[11,13,22,23] Further, the consequences of asymmetrical lower extremity force applications may be an increased fall risk.[23,24]

Upper extremity assistance during the STS task may reduce the force required by the lower extremities and/or provide stability at seat-off, which would explain why it is a common compensation.[4,18,23] Peak upper extremity assistance during an STS task occurs when the buttock is no longer in contact with the chair (seat-off). At the instant of seat-off, there are increased hip and knee joint moment requirements and stability is reduced. The effect of upper extremity assistance is to decrease the required hip and knee extension moments.[3,24] Researchers have examined the direction and magnitude of the upper extremity force contributions in elderly participants.[2,23] In these studies, older individuals who were unable to rise without upper extremity assistance used their upper extremities to keep their body's center of mass in a more stable position (the ground reaction forces [GRFs] being anteriorly directed), as opposed to help decreasing the required lower extremity moments (GRFs directed vertically).[2,23] In elderly participants post–hip fracture who have strength deficits combined with balance problems, it is unknown how upper extremity assistance influences lower extremity force during an STS task. A previous study demonstrated low side-to-side symmetry and less force application on the involved side during an STS task with upper extremity assistance.[13] The results of this previous study raise the possibility that upper extremity assistance in individuals post–hip fracture may not change dependence on the uninvolved limb. However, the study did not compare STS with and without upper extremity assistance. In the present analysis, the focus is on comparing the influence of task difficulty on lower extremity force applications, with the STS task with upper extremity assistance being considered an easier task than the STS task without upper extremity assistance.

Therefore, the purpose of this study was to compare symmetry of lower extremity force applications between the involved and uninvolved sides during an STS task with and without upper extremity assistance in participants post–hip fracture and elderly controls. It was hypothesized that symmetry would improve in participants with hip fractures when performing the STS task with upper extremity assistance. The uninvolved lower-limb GRFs were hypothesized to be similar between participants with hip fractures and controls across both STS tasks.

TABLE 1 DEMOGRAPHICS*

Variable	Control (n = 14)	Post–Hip Fracture (n = 14)	*P* Value
Demographic measures			
Age, y	71.6 ± 8.9	74.2 ± 6.8	.402
Mass, kg	70.4 ± 9.9	70.2 ± 13.8	.957
Body mass index, kg/m^2	25.8 ± 4.2	25.6 ± 4.2	.907
Height, m	1.7 ± 0.1	1.7 ± 0.1	.779
Gender, n	1 M, 13 F	4 M, 10 F	.214
Time since fracture, mo	...	4.1 ± 2.2	...
Clinical measures			
Timed up-and-go, s	7.81 ± 1.22	12.4 ± 4.20	.001†
Gait speed, m/s	2.15 ± 2.20	0.93 ± 1.40	.057
Global performance measures			
Sit-to-stand time UE assist, s	1.21 ± 0.20	1.51 ± 0.52	.051
Sit-to-stand time no UE assist, s	1.26 ± 0.18	1.40 ± 0.39	.269

Abbreviations: F, female; M, male; UE, upper extremity.
**Data are mean ± SD unless indicated otherwise.*
†Significantly different between groups, $P<.05$.

METHODS

Participants

A convenience sample of 28 participants, who were community-dwelling elderly, participated in the study. Most of them (n = 24) were also participants in a recently published study.[13] The 4 participants from the original study who could not complete the STS task without upper extremity assistance were replaced by 4 new individuals who could. Half of the subjects (n = 14) had recovered from a hip fracture and the other half (n = 14) were elderly controls with no history of a hip fracture. Participants post–hip fracture were recruited from a local hospital and were 2 to 12 months postfracture. Descriptive and clinical data for the sample are shown in **TABLE 1**. Inclusion criteria for the hip fracture group were having a hip fracture within the previous 12 months, being functionally independent, and having been discharged from physical therapy care. Exclusion criteria for both groups were a known neurologic diagnosis, documented osteoarthritis of the hip or knee (eg, on medications for joint pain or radiographic evidence of osteoarthritis), severe visual impairments, vestibular disorders, or peripheral neuropathy. Seven participants post–hip fracture had a partial hip replacement (femoral head component), and 7 had open reduction internal fixation. Participants post–hip fracture also had deficits noted on clinical measures of function (**TABLE 1**). Recruitment and study procedures were approved by the Research Subjects Review Board of the University of Rochester.

Sit-to-Stand Task

A custom-built chair, with an adjustable seat height of 45 to 60 cm in 5-cm increments, was adjusted to approximate a 90°/90° hip/knee flexion angle when the subject was seated (**FIGURE 1**). During the STS task with upper extremity assistance, the participant's hands were placed at the edge of the arm rest, fixed at a height of 20 cm above the seat. For the STS task without upper extremity assistance, the participant's hands were placed across the chest (**FIGURE 2**). Participants were seated on the front half of the instrumented chair, with the mid-length of the thighs aligned with the edge of the chair and ankles placed in approximately 15° of dorsiflexion. Participants were instructed to stand up "as quickly as possible." One practice trial was performed, then data were recorded from 3 STS trials with upper extremity assistance (STS upper extremity assist) and 3 trials without upper extremity assistance (STS no upper extremity assist). No participant reported pain during any of the testing sessions.

Four force plates (2 model 92868 and 2 model 9865C; Kistler Instrument Corp, Amherst, NY), integrated into a custom-built chair (**FIGURE 1**), were used to capture the vertical ground reaction force (vGRF). Two force plates, placed flush with the floor, recorded vGRF under each limb (vGRF involved and vGRF uninvolved). The chair was placed on top of a force plate that recorded the force acting through the chair (vGRF chair), which was the sum of forces contributed by the participant's body weight and arms. Another force plate mounted on the seat

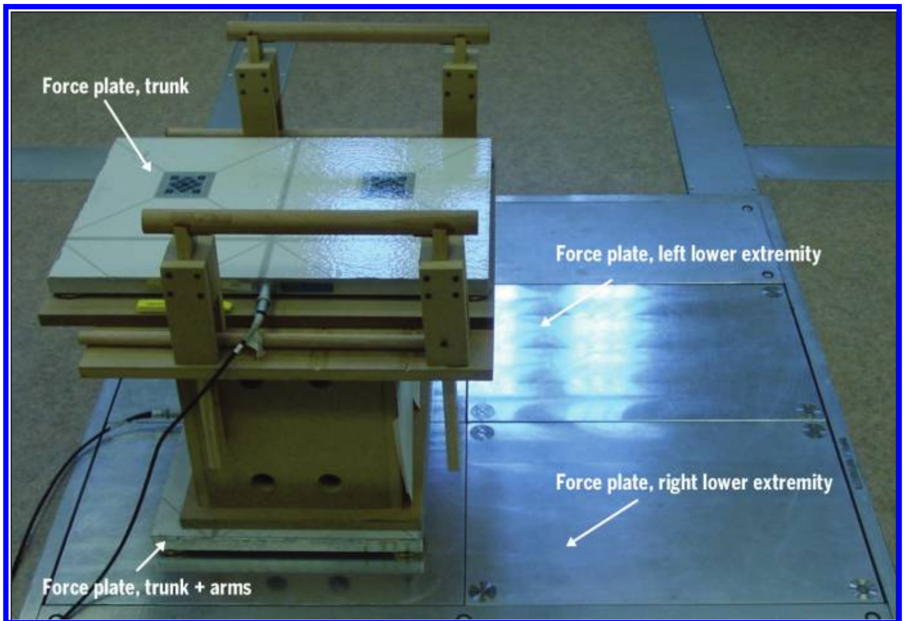

FIGURE 1. The instrumented chair incorporated 4 force plates to measure vertical ground reaction forces under the seat, chair, right lower extremity, and left lower extremity.

FIGURE 2. Sit-to-stand with upper extremity assist (A) and sit-to-stand without upper extremity assist (B) starting positions.

(vGRF seat) recorded vGRF under the participant's buttocks. During data collection, the vGRF of each force plate was recorded at a sampling rate of 1000 Hz with MotionMonitor software (Innovative Sports Training, Inc, Chicago, IL). A digital video camera (model DCR-TRV240; Sony Electronics Inc, San Di-

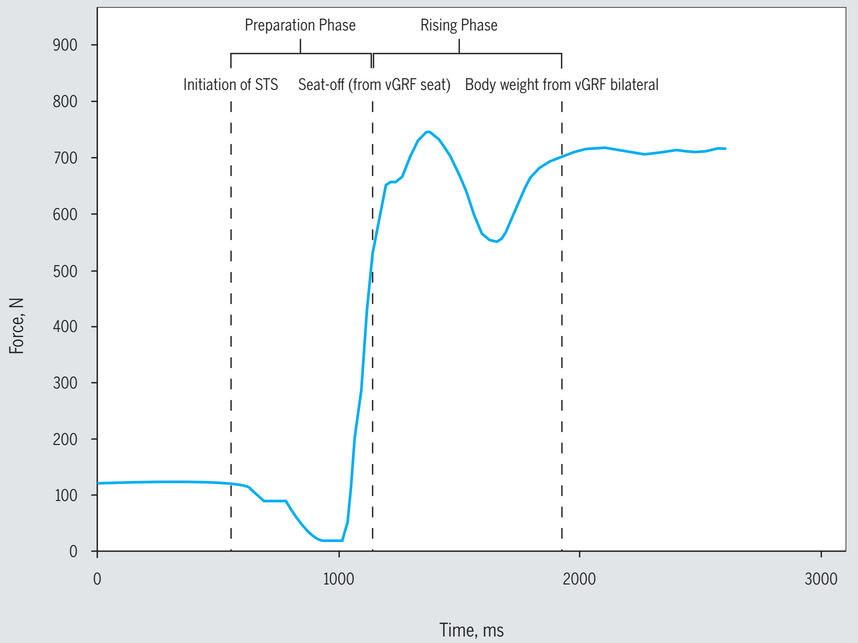

FIGURE 3. The summed vertical ground reaction forces under the right and left lower extremity (vGRF bilateral) are shown. Task initiation and the end of the rising phase were determined from vGRF bilateral. Seat-off, which determines the transition point between the preparation and rising phases, was determined from the seat force plate (vGRF seat). Abbreviations: STS, sit-to-stand; vGRF, vertical ground reaction force.

ego, CA), synchronized with vGRF data, recording at a rate of 30 frames per second, was used to acquire a sagittal plane video of participants during the STS task.

Phases of Sit-to-Stand Task As in recent studies,[9,14,15] 2 phases of the STS task were identified from the sum of vGRF involved and vGRF uninvolved (vGRF bilateral) (**FIGURE 3**). The preparation phase was considered to begin when there was a 5-N decrease in vGRF bilateral. This brief unweighting of the limbs is a countermovement that always precedes the rapid loading of the limbs. The end of the preparation phase occurs at seat-off, marked as the instant when vGRF seat is below 5 N. The rising phase begins at seat-off and ends when vGRF bilateral equals body weight, subsequent to the first peak of vGRF bilateral (**FIGURE 3**). The STS time was measured from the beginning of the preparatory phase to the end of the rising phase.

Lower Extremity Force Variables

Unilateral lower extremity movement strategies were identified from the lower extremity force data. During the preparation phase, the rate of force development (RFD) in Newtons per second (N/s) for the involved (RFD involved) and uninvolved (RFD uninvolved) limb was calculated as the slope between 25% and 50% of the vGRF achieved at seat-off (**FIGURE 4**).[9,15] Side-to-side symmetry in RFD for the preparation phase was assessed by the ratio of the RFD of the involved limb to the RFD of the uninvolved limb (RFD involved:RFD uninvolved). Finally, the impulse (area under the vGRF curve) for the rising phase for each lower limb was calculated based on the respective vGRF curve (**FIGURE 4**). The vGRF impulse symmetry during the rising phase was assessed by the ratio of vGRF impulse of the involved limb to vGRF impulse of the uninvolved limb (vGRF impulse involved:vGRF impulse uninvolved). For both symmetry measures, a value of 1 represents perfect symmetry, indicating that RFD and vGRF impulse are equal bilaterally. Test-retest reliability, using intraclass correlation coefficients, was previously established for the lower extremity force variables and ranged from 0.82 to 0.91 for individuals post–hip fracture and from 0.73 to 0.90 for controls.[12]

Data Analysis

An a priori power analysis using an effect size of 0.98 N·s/kg for vGRF impulse determined that 14 subjects were adequate for the study. All vGRF data were normalized to body mass. The average of the 3 trials for each task was used in the analysis. There were no significant differences attributable to side for any of the lower extremity force variables (t test, $P>.05$) in the control group, so the right side was labeled as the involved side for all subjects in the control group. The first analysis used a mixed 2-way analysis of variance to compare lower extremity force variables when participants used their upper extremities to those when participants did not use their upper extremities. The 2 factors of the 2-way analysis of variance were group (subjects post–hip fracture and controls) and STS task (with and without upper extremity assistance). The dependent variables were RFD involved, RFD uninvolved, RFD symmetry, vGRF impulse involved, vGRF impulse uninvolved, and vGRF impulse symmetry. For each analysis, if a significant group-by-task interaction was present, it was followed by pairwise comparisons and main effects were ignored. A significant interaction for the variables RFD symmetry and vGRF impulse symmetry would be consistent with the hypothesis that the extent of symmetry between lower extremity force applications was dependent on the STS task. Alternatively, significant main effects for group for the variables RFD symmetry and vGRF impulse symmetry would indicate that symmetry persists regardless of the STS task. Because STS time with upper extremity assistance approached significance between groups (**TABLE 1**), the STS time with upper extremity assistance was used as a covariate in all analyses. SPSS Version 17 (SPSS Inc, Chicago, IL)

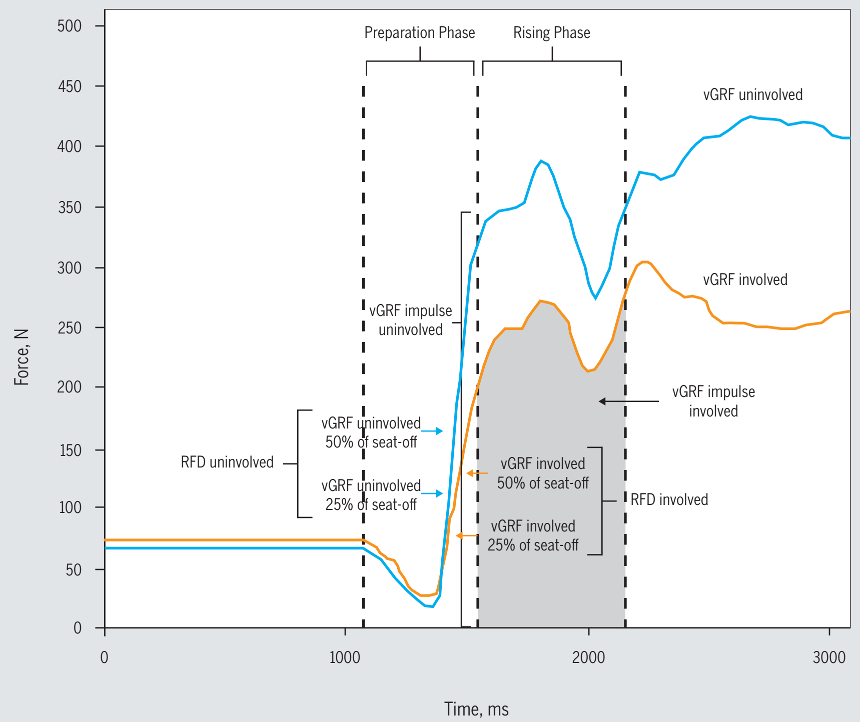

FIGURE 4. The unilateral measures of vertical ground reaction forces for the involved (orange line) and uninvolved (blue line) sides were determined from 2 force plates located under each foot. The RFD during the preparation phase was calculated as the slope from 25% to 50% of the force value at seat-off. RFD symmetry is RFD involved/RFD uninvolved. vGRF impulse was calculated during the rising phase. vGRF impulse symmetry is vGRF impulse involved/vGRF impulse uninvolved. Abbreviations: RFD, rate of force development; vGRF, vertical ground reaction force.

software was used to perform all analyses.

RESULTS

The magnitude of several lower extremity force variables was significantly lower on the involved side for the post–hip fracture group compared to the matched limb of the control group for both STS tasks (**TABLE 2**). During the preparation phase, averaging the data for each group across both tasks, RFD involved was 29.35 N/s/kg for the post–hip fracture group compared to 41.25 N/s/kg for the control group (*P* = .006). However, the magnitude of RFD uninvolved was not significantly different (*P* = .752) between groups (post–hip fracture, 41.8 N/s/kg; control, 40.5 N/s/kg). Consequently, there was a significant main effect (*P*<.001) for RFD symmetry, with the value for the post–hip fracture group (0.72) being smaller than that for the control group (1.05), which was, as expected, near 1.0.

During the rising phase, there was a group main effect (*P* = .045) for vGRF impulse involved, with the value for the post–hip fracture group (4.00 N·s/kg) being smaller than that for the control group (4.61 N·s/kg). However, there was a significant group-by-task interaction (*P* = .039) for vGRF impulse uninvolved. Post hoc analysis showed significantly (*P* = .001) higher vGRF impulse uninvolved for the post–hip fracture group compared to the control group during the STS no upper extremity assist task (**TABLE 2**). Finally, there was a significant group main effect (*P*<.001) for vGRF impulse symmetry, indicating a smaller value for the post–hip fracture group (0.76) versus the control group (1.08), which, as expected, had a symmetry value near 1.0.

DISCUSSION

The main finding of this study showed a lower reliance on the involved limb, irrespective of upper extremity assist, which leads to decreased side-to-side symmetry of lower extremity force applications across STS tasks in participants after a hip fracture. It was anticipated that upper extremity assistance might help improve any side-to-side lower extremity force application differences, but this did not occur. The lack of improvement in lower extremity force application symmetry with upper extremity assistance to perform the STS task in the group post–hip fracture occurred despite adjusting for STS time, which was entered as a covariate in all analyses. During the preparation phase, participants post–hip fracture had lower RFD in the involved limb during both tasks, which resulted in a lower RFD symmetry. During the rising phase, the participants post–hip fracture had a lower vGRF impulse on the involved side for both tasks and a higher vGRF impulse on the uninvolved side for the STS task without upper extremity assistance. The overall effect was significantly lower vGRF symmetry across both STS tasks in the post–hip fracture group. Together, these data show increased reliance on the uninvolved limb in both preparation and rising phases of the STS task, irrespective of upper extremity assistance.

Role of Upper Extremity Assistance

Upper extremity assistance did not improve symmetry of vGRF variables between the involved and uninvolved limbs in the participants post–hip fracture. Consistent with the findings of other studies, upper extremity assistance reduced the magnitude of the lower extremity vGRF during the STS task when compared to the STS task without upper extremity assistance.[3,13] Our findings for the control group are consistent with

TABLE 2 Vertical Ground Reaction Force Data During an STS Task With and Without UE Assistance*

	STS UE Assist		STS No UE Assist			
	Elderly Control	Post–Hip Fracture	Elderly Control	Post–Hip Fracture	Main Effect of Group, *P* Value	Interaction Effect (Group by STS Task), *P* Value
Preparation phase						
RFD involved, N/s/kg	34.4 ± 13.1	24.5 ± 8.5	48.1 ± 11.4	34.2 ± 11.5	.006†	.418
RFD uninvolved, N/s/kg	33.4 ± 8.9	33.5 ± 9.7	47.6 ± 15.3	50.1 ± 11.0	.752	.683
RFD symmetry	1.05 ± 0.36	0.73 ± 0.19	1.04 ± 0.30	0.70 ± 0.19	<.001†	.600
Rising phase						
vGRF impulse involved, N·s/kg	4.55 ± 0.29	3.95 ± 0.64	4.68 ± 0.51	4.24 ± 0.80	.045†	.413
vGRF impulse uninvolved, N·s/kg	4.25 ± 0.40	5.15 ± 1.20	4.36 ± 0.34	5.78 ± 1.10		.039‡
vGRF symmetry	1.08 ± 0.13	0.78 ± 0.13	1.08 ± 0.15	0.74 ± 0.15	<.001†	.625

Abbreviations: RFD, rate of force development; STS, sit-to-stand; UE, upper extremity; vGRF, vertical ground reaction force.
**Data are mean ± SD adjusted for sit-to-stand time.*
†Indicates significant differences (main effect) between groups.
‡Post hoc analysis showed significantly (P = .001) higher vGRF impulse uninvolved for the post–hip fracture group compared to the elderly control group during the STS no UE assist task.

those of similar studies that reported upper extremity contribution to decrease required knee extension moment by 20% to 30%.[2,3] The STS task without upper extremity assistance requires greater lower extremity force output than the STS task with upper extremity assistance. This study determines the influence of this difference in task difficulty associated with upper extremity support on participants recovering from a hip fracture. A previous analysis of similar participants demonstrated greater reliance on the uninvolved side and upper extremity assistance in participants with a hip fracture.[13] What is surprising in this comparison across STS tasks is that the preference for the uninvolved side is not dependent on task difficulty. In the preparation phase, participants with hip fracture showed lower symmetry associated with RFD (0.72) during both the less difficult (STS upper extremity assist) and more difficult (STS no upper extremity assist) tasks, whereas the control group demonstrated nearly identical RFD (1.05) during both tasks. Similarly, during the rising phase, vGRF impulse symmetry was lower for the post–hip fracture group compared to the control group during both STS tasks (**TABLE 2**).

Interestingly, vGRF values for the involved side increased when performing the STS no upper extremity assist task compared to the STS upper extremity assist task, indicating that participants post–hip fracture had the capacity for greater force application by the involved limb during the STS upper extremity assist task. In fact, the magnitudes of the vGRF variables for the involved side (RFD involved and vGRF impulse involved) during the STS no upper extremity assist task were similar to the values for the uninvolved side (RFD uninvolved and vGRF impulse uninvolved) during the STS upper extremity assist task. Additionally, the RFD and vGRF impulse (involved and uninvolved) for the control group during the STS upper extremity assist task were similar to the RFD involved and vGRF impulse involved for the post–hip fracture group during the STS no upper extremity assist task (**TABLE 2**). This suggests that the involved side for the group post–hip fracture had sufficient force capacity to achieve symmetry of force application between limbs when performing the STS task with upper extremity assistance. Why greater force on the involved side was not used during the STS upper extremity assist task is unclear. However, one possibility is that learned movement patterns associated with the recovery of fracture lead to avoidance of force application on the involved side.

Influence of Acute Injury on Symmetry

Decreased symmetry of lower extremity force application may be due to a learned movement pattern. Studies of STS tasks document decreased symmetry of lower extremity force as a result of long-standing pain, weakness, and compensation associated with osteoarthritis of the hip and knee.[10,26] These chronic causes of lower symmetry can be the result of prolonged weakness or learned movement patterns that occur over long periods.[10,27] However, lower symmetry that occurs as a result of an injury such as a hip fracture would be expected to resolve as pain decreases and adequate force production is restored. This study suggests that adequate force capacity was available to achieve symmetry but was not utilized. Whether residual impairments, such as pain, limb-length differences, or weakness, contributed to the alterations in movement patterns was not determined in this study.

Consequences of Lower Symmetry

The participants in this study who were post–hip fracture consistently selected a movement strategy in which loading on the involved lower extremity was about 25% to 30% less than that on the uninvolved side, regardless of task difficulty. If the same asymmetrical lower extremity movement strategy extends to other less stable situations, it could potentially contribute to falls. Based on the moderate to high scores on the timed up-and-go test, the participants in this study who were post–hip fracture appear to be achieving their independence with decreased contributions from the involved limb, resulting in higher relative contributions from the uninvolved side. Asymmetrical lower extremity movement strategies are not unique to the hip fracture population. In a recent article that included individuals post–anterior cruciate ligament injury, the asymmetrical knee extensor moment predicted future anterior cruciate ligament injuries.[21] Additional studies had similar symmetry findings for populations that included knee osteoarthritis and post–anterior cruciate ligament reconstruction.[19,20] However, these individuals vary significantly in age and injury from participants of this study. For individuals post–hip fracture, it is unclear whether current clinical protocols are aimed at increasing symmetry of lower extremity force variables and whether improving symmetry is important both clinically and functionally. Future studies should focus on clinical interventions for improving lower extremity symmetry and document the prognostic value of symmetry for falls and physical function after a hip fracture.

Limitations

Limitations of this study include the cross-sectional design and failure to control STS time between groups. It is possible that alterations in lower extremity force variables were present prior to the hip fracture; however, participants were screened for a variety of health conditions (eg, unilateral osteoarthritis of the hip or knee) previously associated with asymmetry during an STS task. To minimize the influence of difference in STS time between groups, it was included as a covariate for all analyses. Future studies may consider controlling STS time; however, this may impact the validity of the study, as it artificially affects the performance of the task.

CONCLUSION

In individuals post–hip fracture, the use of upper extremity assistance during an STS task does not improve symmetry of lower extremity force contribution to the task, with the involved lower extremity consistently contributing 25% to 30% less than the uninvolved side. These data suggest that lower extremity movement strategies employed by individuals post–hip fracture who were recently discharged from home-care physical therapy include a high dependence on the uninvolved lower limb, despite a return to relatively normal function and independence. ◉

KEY POINTS

FINDINGS: Older individuals post–hip fracture who were discharged from rehabilitative care maintained a consistent dependence on the uninvolved limb irrespective of whether upper extremity assistance was included for an STS task.

IMPLICATIONS: These findings suggest that learned motor-control strategies associated with the involved limb influence movement post–hip fracture.

CAUTION: The cross-sectional design of this study cannot determine cause-and-effect relationships, and STS time was not controlled, which may influence the lower extremity force data.

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