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Association of Shoulder Dysfunction with Mobility Limitation Among Older Adults in the Baltimore Longitudinal Study of Aging

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Abstract

Association between lower extremity dysfunction and mobility limitation in older adults is well-established; whereas, the impact of upper extremity dysfunction on mobility remains unclear. Since lower extremity dysfunction does not explain all mechanisms that contribute to mobility limitation, more holistic hypotheses that explain reduced mobility in older populations are needed. The shoulders facilitate dynamic stability for ambulation, but the impact of shoulder dysfunction on mobility is poorly understood. This study examined the cross-sectional association of restricted shoulder elevation and external rotation range of motion (ROM) with poor lower extremity function and walking endurance capacity among 613 older adults aged 60 years and older in the Baltimore Longitudinal Study of Aging. Results showed that persons with abnormal shoulder elevation or external rotation ROM were 2.5 to 4.5 times more likely to perform poorly on the expanded Short Physical Performance Battery ($p < .050$) and the fast-paced 400 m walk test ($p < .050$), relative to participants with normal shoulder ROM. These findings provide nascent preliminary evidence that shoulder dysfunction is associated with mobility limitation and suggest that future studies are needed to clarify its impact on mobility and to develop novel interventions to improve prevention or mitigation of age-related declines in mobility.

Keywords

lower extremity function, older adults, range of motion, shoulder, walking endurance

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Introduction

Mobility limitation affects more than one-third of older adults and is a major burden on public health in the United States (U.S. Centers for Medicare & Medicaid Services, 2011). Lower extremity dysfunction is a well-known cause of mobility limitation in older populations (Guralnik et al., 1994, 1995, 2000; Vasunilashorn et al., 2009). Although mitigation of poor lower extremity performance is a common goal, investigators now recognize that lower extremity dysfunction alone fails to fully explain all mechanisms that contribute to mobility limitation and now advocate for development of more holistic scientific hypotheses that expound how gait biomechanics facilitate reduced mobility in older populations (Boyer et al., 2023). In 2021, to prioritize this issue, The United States National Institute on Aging (NIA) invited scientists and clinicians to a 2-day multidisciplinary work shop with the task of identifying knowledge gaps about the causes and consequences of age-related declines in gait biomechanics and also of identifying areas of future research, innovation and collaboration toward improved mitigation of age-related mobility limitation (Boyer et al., 2023). Mitigation of reduced mobility is a major goal toward maintaining functional independence, and discovery of novel or overlooked risk factors for mobility limitation should be prioritized (Guralnik et al., 2000; Shah et al., 2010; Vasunilashorn et al., 2009).

Coordinated movements of the upper and lower extremities facilitate normal gait biomechanics, and the upper extremities provide dynamic stability during

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ambulation. In a holistic sense, upper extremity dysfunction via maladapted arm swing is one potential mechanism contributing to altered gait biomechanics (Krasovsky et al., 2012). Mobility disability has known association with dysfunctional arm swing among persons with acquired central nervous system (CNS) disorders (Collins et al., 2009; Kwakkel & Wagenaar, 2002; Roemmich et al., 2013). However, there is a gap in knowledge about the presence and strength of the association between upper extremity dysfunction and mobility limitation among community-based populations of older adults.

The shoulder is the upper extremity's link to the trunk and facilitates arm swing during ambulation. However, the shoulder is susceptible to progressive age-related dysfunction. An estimated 20% of older adults experience shoulder pain in the United States and one in four older adults have a rotator cuff tear (Patel et al., 2013; Yamamoto et al., 2010). Shoulder dysfunction also has well-known association with restricted range of motion (ROM) (Baumer et al., 2016; Kuhn et al., 2013). Yet, the strength of association for shoulder dysfunction with lower extremity performance or walking endurance capacity in older populations is poorly understood.

The Baltimore Longitudinal Study of Aging (BLSA), a continuous community-based longitudinal observation study conducted by intramural investigators of the NIA, collected shoulder ROM data during standardized physical examination visits over a 10-year period. This study represents the first nascent analysis of objective shoulder ROM data in the BLSA cohort. One objective of this study is to begin a general conversation about the association of restricted shoulder ROM with measures of lower extremity performance and walking endurance capacity in a well-established community-based cohort of older adults, in keeping with the view that more holistic strategies for research on mobility may hold promise for improving prevention or mitigation of mobility limitation in older populations.

We performed a cross-sectional study among older adults in the BLSA to examine associations of restricted shoulder elevation ROM rating and shoulder external rotation ROM rating with poor performance on the expanded Short Physical Performance Battery (eSPPB) and fast-paced 400 m walk test (400MWT), using BLSA physical examination, physical performance battery, and walking test datasets. We tested the hypothesis that restricted shoulder ROM rating, as a marker of shoulder dysfunction, is associated with poor lower extremity performance and poor walking endurance capacity.

Methods

Study Design

Data are from the BLSA, a continuous prospective longitudinal cohort study conducted by the Intramural Research Program of the NIA since 1958. The BLSA cohort is composed of adults ≥20 years who primarily live in the region of Washington, D.C., and Baltimore, Maryland. Details of the study protocol and BLSA cohort have been described elsewhere (Shock et al., 1984). Between 2006 and 2015, the BLSA rated shoulder ROM during physical examination and conducted physical performance testing (Baltimore Longitudinal Study of Aging (BLSA), 2014; Ferrucci et al., 1995). For this analysis we used data from participants who were 60 years or older during the BLSA visit when the shoulder examinations were initially performed. There were 613 participants aged 60 to 97 years who completed bilateral shoulder elevation ROM and/or bilateral shoulder external rotation ROM testing and the fast-paced 400MWT and/or eSPPB. Just over half the sample was male. Written informed consent was obtained from all participants. This secondary analysis was defined as not human subjects research by the University of Maryland Institutional Review Board.

Shoulder Range of Motion

Jette and Branch proposed and validated a 3-point ordinal scale for objectively measuring musculoskeletal impairments as a method suitable for evaluation of older adults in large-scale community based studies with participants in the Massachusetts Health Care Panel Study, a longitudinal observational study (Jette & Branch, 1984, 1985). Included in the panel of musculoskeletal assessments was shoulder ROM, which rated participant's performance as fully able, partially able, or unable to complete the requested movement (Jette & Branch, 1984, 1985). This 3-point ordinal scale was further validated for shoulder ROM in the NIA's Women's Health and Aging Study and subsequently included as a formal physical assessment measure in the BLSA by NIA intramural investigators (Baltimore Longitudinal Study of Aging (BLSA), 2014; Ferrucci et al., 1995).

Between 2006 and 2015, the BLSA general physical examination standardized protocol included shoulder ROM testing by study certified registered nurse practitioners (CRNPs). The BLSA's physical examination protocol follows rigorous training, certification and regular re-certification to optimize reliability for physical examination assessments. All study CRNPs re-certify with a BLSA staff physician for all standardized physical examination assessments, inclusive of shoulder ROM testing, on a semi-annual basis (Baltimore Longitudinal Study of Aging (BLSA), 2014).

During standardized physical examination assessment, a CRNP evaluated shoulder elevation ROM by instructing the participant: "Please lift your hands directly in front of you as high as you can with your thumbs pointing up." The CRNP rated the left shoulder and right shoulder separately, and rated each shoulder as "fully able," "partially able," or "unable" to complete the task of shoulder elevation (Baltimore Longitudinal Study of Aging (BLSA), 2014; Ferrucci et al., 1995). "Fully able" was defined as the participant demonstrating full shoulder elevation; "partially able" was defined as some shoulder motion but less than full shoulder elevation; "unable" was defined as an inability to demonstrate any motion toward shoulder elevation. A CRNP evaluated shoulder external rotation ROM by instructing the participant: "place both hands behind your neck at the level of the ears, with the arms parallel to the floor and elbow pointed out to the sides at 180 degrees from the body." The CRNP rated the left shoulder and right shoulder separately, and rated each shoulder as "fully able," "partially able," or "unable" to complete the task of shoulder external rotation, using the same 3-point ordinal scale: "fully able," "partially able," or "unable" (Baltimore Longitudinal Study of Aging (BLSA), 2014; Ferrucci et al., 1995).

Walking Endurance Capacity

Walking endurance capacity was measured in seconds as a continuous variable for time to complete a fast-paced 400 m walk, as determined by a BLSA exercise physiologist. Participants were instructed to ambulate "as quickly as possible at a pace that can be maintained" for 10 laps on a 40 m uncarpeted course (Simonsick et al., 2006, 2014). Poor performance was defined as the fourth (slowest) quartile of 400MWT time.

Lower Extremity Performance

Lower extremity performance was measured by eSPPB score (4, best; 0, worst) as a continuous variable, as determined by a BLSA exercise physiologist (Simonsick et al., 2016). The eSPPB score is the sum of four components: usual-pace 6 m walk, five repeated chair stands, standing balance, and a 6 m narrow walk test all scored on a ratio scale from 0 to 1 where 1 equals attained maximal performance and 0.5 represents the 50th percentile performance. Poor performance was defined as the fourth (worst) quartile of eSPPB score.

Covariates

Covariates included age, sex, height, weight, and number of chronic conditions. Age and sex were recorded via BLSA interview questionnaire. Height and weight were measured without wearing shoes by the Detecto Medical Beam Scale. The presence or absence of chronic conditions was recorded via facilitated self-report by BLSA interview questionnaire. Chronic conditions included history of myocardial infarction, congestive heart failure, angina, bronchitis, asthma, diabetes mellitus, peripheral vascular disease, and peripheral arterial disease.

Statistical Analysis

Participants who were "fully able" to complete the task of shoulder elevation ROM at both shoulders were defined to have a normal shoulder elevation ROM rating. Participants who were not "fully able" to complete the task of shoulder elevation ROM at both shoulders were defined to have an abnormal shoulder elevation ROM rating. Participants who were "fully able" to complete the task of shoulder external rotation ROM at both shoulders were defined to have a normal shoulder external rotation ROM rating. Participants who were not "fully able" to complete the task of shoulder external rotation ROM at both shoulders were defined to have an abnormal shoulder external rotation ROM rating. For the primary analyses, the odds of poor performance (defined as fourth quartile performance) on the 400 m walk or eSPPB score associated with abnormal shoulder elevation ROM rating relative to normal shoulder elevation ROM rating or abnormal shoulder external rotation ROM rating relative to normal shoulder external rotation ROM rating were determined in separate analyses using logistic regression adjusted by age, sex, height and weight in model 1 and adding number of chronic conditions stratified into three categories: 0, 1, or ≥ 2 in model 2. Descriptive statistics were reported as mean ± standard deviation or as n (%). Chi-squared test and Cramer's V test were performed as appropriate. Analyses were conducted using SAS software version 9.4 (SAS Institute Inc., Cary, North Carolina).

Results

Mean age was 71.81 ± 8.04 years, with males accounting for 50.4% (309/613) of the study population. The frequency of abnormal shoulder elevation ROM rating and abnormal shoulder external ROM rating in the study population were 6.85% (42/613) and 4.08% (25/613), respectively. Characteristics of participants by shoulder ROM rating are summarized in Table 1.

Shoulder ROM Rating and Lower Extremity Performance

Forty-one (8.9%) of 462 participants who completed bilateral shoulder elevation ROM testing and the eSPPB demonstrated abnormal shoulder elevation ROM rating. Twenty-four (5.2%) of 459 participants who completed bilateral external rotation ROM testing and the eSPPB demonstrated abnormal shoulder elevation ROM rating. The number of participants with abnormal ROM rating per quartile of eSPPB score are summarized in Table 2. For quartile of eSPPB score and shoulder elevation ROM rating, Cramer's $V = 0.25$, $p < .001$. For quartile of eSPPB score and shoulder external rotation ROM rating, Cramer's $V = 0.21$, $p < .001$).

Participants with abnormal shoulder elevation ROM rating had a crude odds of five times ($p < .001$), and an adjusted odds of 3.2 times ($p = .004$), the likelihood of being in the worst performance quartile relative to those with normal bilateral shoulder elevation ROM rating

Table 1. Characteristics of the Study Sample Stratified by Normal and Abnormal Shoulder Range of Motion Rating.

	Shoulder elevation ROM rating (*n* = 463)			Shoulder external rotation ROM rating (*n* = 459)		
	Normal (*n* = 421)	Abnormal (*n* = 42)	*p*	Normal (*n* = 434)	Abnormal (*n* = 25)	*p*
Age, years	69.52 ± 7.16	74.98 ± 8.50	<.001	71.74 ± 8.33	75.64 ± 7.62	.023
Male, *n*	218 (51.8%)	28 (66.7%)	.065	218 (50.2%)	11 (44.0%)	.545
Height, m	1.69 ± 0.09	1.72 ± 0.08	.035	1.68 ± 0.09	1.68 ± 0.10	.949
Weight, kg	78.76 ± 15.39	83.55 ± 16.71	.057	76.56 ± 14.83	79.35 ± 16.88	.364
CC, *n*			.106			.118
0	25 (5.9%)	0		33 (7.6%)	0	
1	81 (19.2%)	5 (11.9%)		99 (22.8%)	3 (12.0%)	
≥**2**	315 (74.8%)	37 (88.1%)		302 (69.6%)	22 (88/0%)	

Note. Values are mean ± standard deviation or *n* (%). ROM = range of motion; CC = chronic conditions.

Table 2. Number of Participants with Abnormal Shoulder Range of Motion Rating Per Quartile of Expanded Short Physical Performance Battery Score.

	Score	Shoulder elevation[a] (%)	Shoulder external rotation[b] (%)
Q1 (Best)	3.68–2.80	*n* = 3 (7.3)	*n* = 1 (4.2)
Q2	2.79–2.55	*n* = 6 (14.6)	*n* = 2 (8.3)
Q3	2.54–2.25	*n* = 8 (19.5)	*n* = 7 (29.2)
Q4 (Worst)	2.24–0.00	*n* = 24 (58.5)	*n* = 14 (58.3)

Note. Q = quartile.
[a]Shoulder elevation range of motion (ROM) rating.
[b]Shoulder external rotation ROM rating.

Table 3. Association of Abnormal Shoulder Range of Motion Rating With Poor Expanded Short Physical Performance Battery Score.

Shoulder ROM[a] rating	Crude			Model 1[c]			Model 2[d]		
	n	OR [95% CI][b]	*p*	*n*	OR [95% CI]	*p*	*n*	OR [95% CI]	*p*
Elevation									
Normal	421	1.00		421	1.00		421	1.00	
Abnormal	41	5.05 [2.60, 9.80]	<.001	41	3.49 [1.58, 7.70]	.002	41	3.20 [1.44, 7.09]	.004
External rotation									
Normal	433	1.00		433	1.00		433	1.00	
Abnormal	24	4.49 [1.93, 10.40]	<.001	24	2.86 [1.11, 7.39]	.030	24	2.51 [0.96, 6.61]	.060

[a]Range of motion.
[b]Odds ratio [95% confidence interval].
[c]Adjusted for age, sex, height, and weight.
[d]Adjusted for age, sex, height, weight, and comorbidity.

(Table 3). Participants with abnormal shoulder external ROM rating had a crude odds of nearly 4.5 times ($p < .001$), and an adjusted odds of nearly 2.5 times ($p = .060$), of being in the worst performance quartile relative to those with normal bilateral shoulder elevation ROM rating.

Shoulder ROM Rating and Walking Endurance

Fourteen (5.5%) of 254 participants who completed bilateral shoulder elevation ROM testing and the fast-paced 400MWT demonstrated abnormal shoulder elevation ROM rating. Seventeen (4.2%) of 401 participants who completed bilateral shoulder external rotation ROM testing and the fast-paced 400MWT demonstrated abnormal shoulder external rotation ROM rating. The number of participants with abnormal ROM rating per quartile of 400MWT time are summarized in Table 4. For quartile of fast-paced 400MWT time and shoulder elevation ROM rating, Cramer's $V = 0.15$, $p = .140$. For quartile of fast-paced 400MWT time and shoulder external rotation ROM rating, Cramer's $V = 0.19$, $p = .002$.

Participants with abnormal shoulder elevation ROM rating had a crude odds of nearly 3.5 times ($p = .030$),

Table 4. Number of Participants With Abnormal Shoulder Range of Motion Rating Per Quartile of Fast-paced 400 m walk time.

	Score (s)	Shoulder elevation[a] (%)	Shoulder external rotation[b] (%)
Q1 (Fastest)	179.8–239.5	*n* = 3 (21.4)	*n* = 2 (11.8)
Q2	239.7–260.0	*n* = 2 (14.3)	*n* = 2 (11.8)
Q3	260.5–291.6	*n* = 3 (21.4)	*n* = 2 (11.8)
Q4 (Slowest)	292.0–593.6	*n* = 6 (42.9)	*n* = 11 (64.7)

Note. Q = quartile; s = seconds.
[a]Shoulder elevation range of motion (ROM) rating.
[b]Shoulder external rotation ROM rating.

Table 5. Association of Abnormal Shoulder Range of Motion Rating With Poor Fast-paced 400 m Walk Performance.

Shoulder ROM rating[a]	Crude			Model 1[c]			Model 2[d]		
	n	OR [95% CI][b]	*p*	*n*	OR [95% CI]	*p*	*n*	OR [95% CI]	*p*
Elevation									
Normal	240	1.00		240			240	1.00	
Abnormal	14	3.44 [1.13, 10.41]	.030	14	4.66 [1.12, 19.49]	.035	14	4.30 [1.01, 18.34]	.048
External rotation									
Normal	384	1.00		384	1.00		384	1.00	
Abnormal	17	6.08 [2.19, 16.90]	<.001	17	4.82 [1.39, 16.74]	.010	17	4.48 [1.26, 15.88]	.020

[a]Range of motion.
[b]Odds ratio [95% confidence interval].
[c]Adjusted for age, sex, height, and weight.
[d]Adjusted for age, sex, height, weight, and comorbidity.

and an adjusted odds of 4.3 times ($p = .048$), of performing in the slowest quartile of the fast-paced 400MWT relative to those with normal bilateral shoulder elevation (Table 5). Participants with abnormal shoulder external rotation ROM rating had a crude odds of six times ($p < .001$), and an adjusted odds of nearly 4.5 times ($p = .020$), of performing in the slowest quartile of the fast-paced 400MWT relative to those with normal bilateral shoulder elevation.

Discussion

Among older adults in the BLSA, the lack of full range of motion for shoulder elevation or shoulder external rotation significantly increased the odds for co-existent poor lower extremity performance or poor walking endurance capacity. The link between shoulder dysfunction and mobility limitation is nascent in description, and this study provides supportive evidence that a significant association exists.

This study's investigation of the association of restricted shoulder ROM with poor mobility performance in a community-based cohort of older adults follows the developing conversation among scientists, clinicians and the NIA that more holistic research strategies are needed to push the field forward to create greater understanding of how age-related challenges to mobility develop in older populations (Boyer et al., 2023). Current concepts about holistic strategies geared toward discovery of novel contributory mechanisms to mobility limitation are logical next steps following the trail blazing LIFE-Pilot and LIFE studies (Pahor et al., 2020). This study is meant to raise awareness and to begin a conversation about whether or not shoulder dysfunction is a precursor for development of abnormal gait and if treatment of shoulder dysfunction might serve as prehabilitation for incident reduced mobility in older populations. Currently, there is poor understanding if treatment of restricted shoulder ROM will prevent or mitigate poor lower extremity performance or poor walking endurance capacity in older population. However, prior to the planning of the LIFE-Pilot and LIFE studies for example, there was also scientific uncertainty as to whether regular physical activity could reduce the risk of developing a major mobility disability (Pahor et al., 2020). Similarly, although there is current limited evidence that identification and treatment of shoulder dysfunction may reduce the risk of mobility limitation in older populations, this study's findings suggest that restrictions in shoulder ROM may negatively impact gait biomechanics; and future scientific investigation is needed to verify this finding and also shoulder dysfunction's holistic global effects on daily physical activity, endurance and mobility in older populations.

Quantifying shoulder dysfunction's contribution to poor lower extremity performance in older populations is a novel concept. Recently, James, Leveille, Hausdorff, Travison, Cote, et al. (2017) and James, Leveille, Hausdorff, Travison, Kennedy, et al. (2017) reported that dysfunctional shoulder coordination may contribute to mobility limitation in older adults. Likewise, our study of BLSA participants provides additional evidence that shoulder dysfunction increases the likelihood of co-existent poor lower extremity performance in older adults, even after adjustment for age, sex, height, weight, and chronic conditions.

Another novel finding of this study was that BLSA participants with shoulder dysfunction showed a higher likelihood of poor walking endurance capacity. Future studies in older populations are warranted to investigate if shoulder dysfunction is associated with increases in gait-related energy expenditure and association with reduced gait speed on walking tests (Boyer et al., 2023). Shoulder dysfunction's impact on the lap time variation and the need to stop and rest during the 400MWT also merit future research.

Our study is not without limitations. Participants unable to complete the fast-paced 400MWT were not included in the analysis, and the study is not generalizable to mobility-disabled populations. Poor performance in the fast-paced 400MWT was not defined by a strict cut-off time point but was instead defined as the slowest (fourth) quartile. Shoulder ROM was rated by a categorical 3-point ordinal scale and not assessed as a continuous measure in degrees. Results of the study reflect the population of older adults in the BLSA and may not be generalizable to the general population. Given the cross-sectional nature of the study design, the presence of reverse causal association is a potential limitations since poor lower extremity function or poor walking endurance capacity may potentially influence the presence of restricted shoulder ROM.

Conclusion

This study suggests that abnormal shoulder ROM is associated with increased likelihood of co-existent poor lower extremity performance or poor walking endurance capacity in older populations. Future research is warranted to determine the longitudinal association of abnormal shoulder ROM rating with lower extremity function and walking endurance capacity, to test if novel incorporation of shoulder functional measures into mobility screening programs improves identification of older adults vulnerable to mobility limitation, and to investigate if treatment of shoulder dysfunction provides effective prehabilitation to prevent or mitigate age-related declines in mobility for older adults.

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Declaration of Conflicting Interests

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Ethical Approval

This project was approved by the University of Maryland Institutional Review Board (HP-00089783).

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